

NEW DESIGN TOOLS FOR A CYCLOTRON CENTRAL REGION

D. Battaglia, L. Calabretta, D. Campo M. Maggiore, L. Piazza, D. Rifuggiato, INFN-LNS, Italy

Abstract

A code that allows us to design the spiral inflector and the central region of the SCENT cyclotron was implemented. The code integrates the main equations of motion of a particle in an electromagnetic field and provides an useful interface to describe the geometry and the physical constraints of the inflector and the central region to be simulated. The mechanical drawings of the inflector and the central region is made using a standard CAD. These drawings are then imported in OPERA 3D to produce the maps of the electric and magnetic field. An application interface allows us to enter the emittance and the particles' distributions to be transported through the inflector. An iterative process to design the central region was also developed and tested.

INTRODUCTION

A design study for a Superconducting Cyclotron for Exotic Nuclei and Therapy (SCENT) is in progress at LNS [1]. This is a four sectors cyclotron working in fourth harmonic which in his previous version had to accelerate light ions, with charge to mass ratio $q/A=0.5$, up to an energy of 250 AMeV. Recently a study to increase its maximum energy up to 300 AMeV has started.

The advantage to minimise the size of the cyclotron using high magnetic field has as a drawback the difficulty to design a very compact central region. The feasibility of the central region practically limits the value of the maximum magnetic field usable. Some new tools to help us in the design of the spiral inflector and of the central region were developed.

INFLECTOR DESIGN

Among the different types of cyclotron's inflectors known the spiral inflector has the main advantage to occupy a small space and for this reason it was selected as inflector for our project.

The properties of the spiral inflector are well known and described in historical references [2-3]. The free parameters of this inflector are the magnetic curvature and the slant angle. The first parameter is related to the value of the electric field while the second one is a mechanical parameter. Although the main parameters of the spiral inflector can be achieved by analytical equations of the central particles it is also very important for the design of a real device to evaluate the transmission efficiency for a beam with realistic emittance and the mechanical size of the inflector.

The main difference between the analytical solution and the real case is due to the fringing field effects [4-5] which change the beam dynamics. At first order it is

possible to compensate the fringing effects in two ways:

1. decreasing the inflector length;
2. changing the electric field between the electrodes.

We chose the second option because to change the electric field, it is only necessary to decrease the potential of the electrodes. This is also the usual operation made to tune the beam injection. Moreover two collimators, near the entrance and the exit of the inflector, connected to ground, allow us to reduce the extension of the fringing fields. All the mechanical parameters like the size of the holes, the distance between the collimators and the inflector, the gap and the aspect ratio of the inflector, affect the trajectories of the beam particles. So the beam particles' trajectories through the electric field have to be simulated to understand these effects.

A code to help us to design the model of the spiral inflector was developed in MATLAB [10]. The code produces an interface which asks us to fill in each field with the parameters of the inflector and of the cyclotron field and of the beam, see Fig. 1.

When all the parameters have been inserted, the code produces different files describing the central trajectory but also some input files for the mechanical drawing code which allows us to generate the mechanical model of the inflector and of its collimators. This model can be imported in the electrostatic simulator of OPERA code [9].

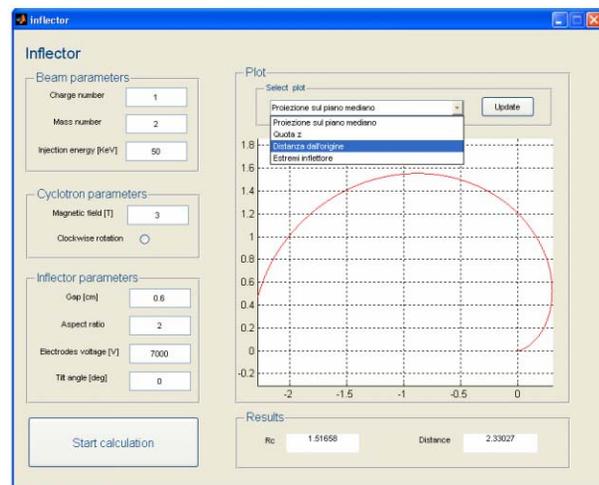


Figure 1: Graphical interface to optimize the inflector design.

Then the boundary conditions to the geometrical structure have to be assigned to simulate the inflector by the 3D code OPERA and to calculate the effective electric field distribution.

The tracking code of OPERA is used to simulate the trajectories of the ions inside the inflector. Fig. 2 shows

the inflector and the particles' trajectories.

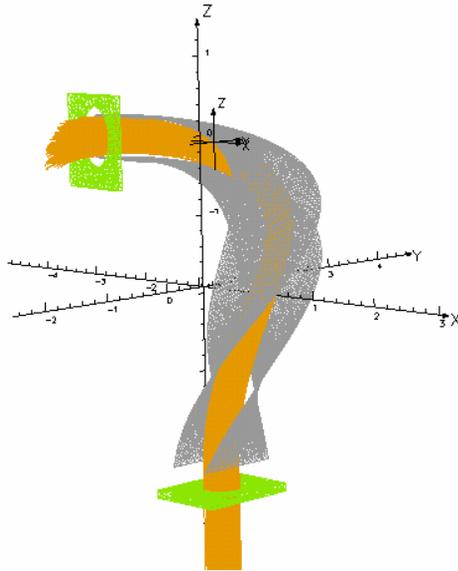


Figure 2: Layout of the spiral inflector crossed by the beam. The electrodes surface are in grey, the collimators are in green and the beam particles in orange.

An additional code allows us to print easily the input file of the particle's coordinates in the phase space. Many parameters of the beam distribution like the size and the position of the beam and also the kind of the distribution, uniform or gaussian, can be selected.

The output files of OPERA code are also handled by the interface code which shows the final beam position and the beam distribution in the transversal plane at the exit position of the inflector.

In Fig. 3 the axial beam emittance of the particles transmitted through the inflector is shown. The transmission efficiency of the simulated inflector is about 98.5%.

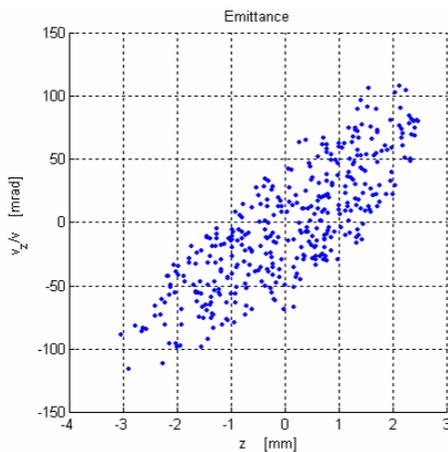


Figure 3: Beam axial emittance at the exit of the inflector.

CENTRAL REGION DESIGN

The central region was designed to optimize the energy gain and the beam centering.

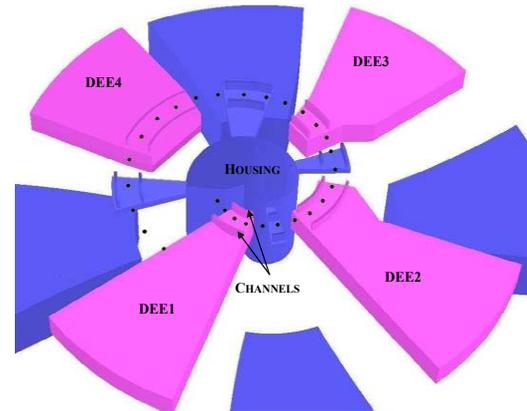


Figure 4: Layout of the central region of SCENT.

The preliminary design of the central region begins with the construction of the reference trajectory. This is done using a CAD and assuming that the energy gain occurs in the middle of each acceleration gap. The coordinates of the particles and their velocity at inflector exit have to be entered too.

We supposed that the trajectory is the union of N arcs of circle, where N is the number of crossed gap. So we determined the position of the center of the arc and the new value of the radius for each crossed gap [6]. Around this trajectory a tentative profile of the dees and dummy dees is drawn. This structure is imported in a 3D electrostatic simulator code, like OPERA to achieve the electric field distribution. The magnetic field maps were evaluated also by the same code.

The electric and magnetic maps are then imported in a dedicated code to evaluate the real trajectory. This code, written in MATLAB environment, allows us to evaluate the beam dynamics integrating the Lorentz's equation $\vec{F} = q(\vec{E} + \vec{v} \times \vec{B})$ using the cartesian coordinates and time as independent variable of integration. An option using the angular azimuth as independent variable of integration is in progress. Looking at the trajectory the drawing of the central region electrodes are modified and a new simulation is restarted.

The code allows us to enter the coordinates, the velocity and the phase of a number of particles.

In the first turn, to improve the effects of the accelerating electric field a channel across each dee is used. These channels allow us to confine the electric field close to the gaps. A radial gap of 8 mm was selected to leave enough space for the beam inside the channel.

The electric field values along the vertical direction are lower than 60% of the Kilpatrick limit [8], because the magnetic field is just along this direction. Along the radial direction, where the magnetic field prevents the electrical discharge, the maximum electric field is up to 1.7 times the Kilpatrick limit.

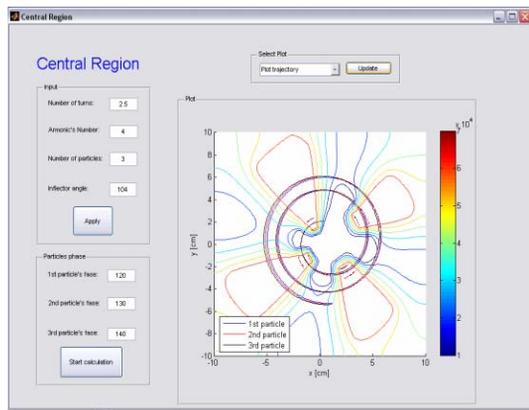


Figure 5: Trajectory of three particles with different phase.

Fig. 5 shows the graphical interface of our code. The outputs of the code are the trajectories, the motion of the trajectories' center, the gain of energy for particle. In this figure the trajectories of three particles with phase ϕ of 120° , 130° and 140° respectively are plotted.

Fig. 6 shows the energy versus the RF phase while in Fig. 7 the motion of the curvature's center in the first turns are shown.

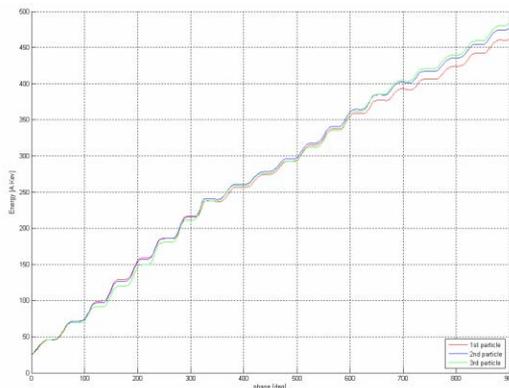


Figure 6: Energy gain of three particles for the first turns.

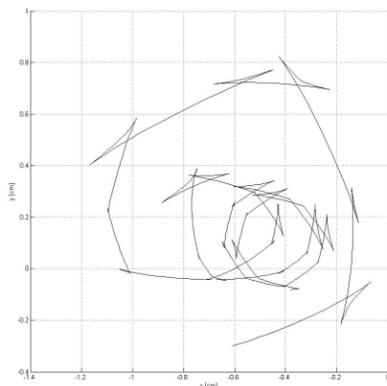


Figure 7: Motion of the curvature's center of one particle.

NUMERICAL RESULTS

In order to check our code we simulated the beam dynamics of the central region of the K800 superconducting cyclotron.

We compared the results with the trajectory obtained from the code Z3CYCLONE [11].

In the Fig. 8 the red line shows the trajectory obtained with our code and the black one shows the result of the Z3CYCLONE simulation. A good matching of the results was obtained. The difference between the trajectories radii is lower than 0.6%.

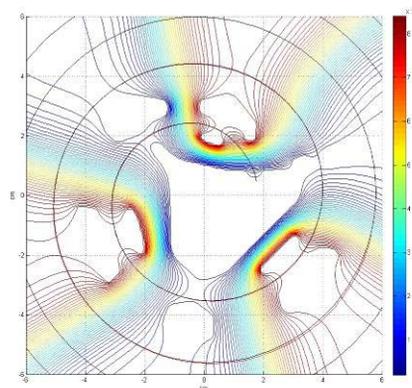


Figure 8: Trajectory calculated with our code (red line) and Z3CYCLONE (black line).

REFERENCES

- [1] L. Calabretta et al., "Preliminary study of the SCENT project" (2005).
- [2] L.W. Root, PhD thesis, Univ. Of British Columbia (1974).
- [3] D. Toprek, "Theory of the central ion trajectory in the spiral inflector". NIM A 440 (2000), pp. 285-295.
- [4] D. Toprek, "Some optical properties of the spiral inflector". NIM A 431 (1999), pp. 38-45.
- [5] L. Milinkovic. RELAX3D Spiral Inflector. TRI-DN-89-21.
- [6] D. Toprek, "Centering of the ion trajectory in the cyclotron". NIM A 480 (2002), pp. 379-386.
- [7] L. Milinkovic, "Design of the central region for axial injection in the VINCY cyclotron". NIM A 370 (1996), pp. 287-296.
- [8] S. O. Schriber et al. "Factors limiting the operations of structures under high gradient". In LINAC 98 (1998).
- [9] OPERA, Vector Fields www.vectorfields.com.
- [10] The MathWorks, Inc. Matlab version 7.1, <http://www.mathworks.com>.
- [11] MSU NSCL, Accelerator Group, Z3CYCLONE Instruction Manual Version 4.1 (1996).