

CENTRAL REGION AND STATIC ORBIT STUDY FOR THE 300 A MEV SUPERCONDUCTING CYCLOTRON

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Abstract

The geometry of electrodes in the central region of the 300 A MeV Superconducting Cyclotron was designed using some commercial tools, as AUTOCAD to draw and OPERA – 2D to simulate the electromagnetic field. A new dedicated MATLAB program was also developed to simulate the particles trajectories. The results obtained by the iterative use of these programs are here reported. An important issue of the cyclotron design is the evaluation of the focusing properties of the magnetic field and of the beam dynamic inside the cyclotron. An integration code for the radial equations of motion was developed in order to find the equilibrium orbits. Besides, a new integration code for the coupled equation in r and z direction is implemented too. All these programs are in MATLAB and Simulink language.

CENTRAL REGION DESIGN

We have studied a preliminary configuration for the central region of the 300 A MeV Superconducting Cyclotron. The placement and shape of the various posts and electrodes are designed to optimize the range of starting conditions for the ions which can be accelerated out of the region.

Our procedure is mainly a graphical method. In the first approximation, according to Toprek's theory [1], the radius gain depends on the energy gain after each gap. So two channels are inserted in each 'Dee' in order to confine the electric field close the gaps.

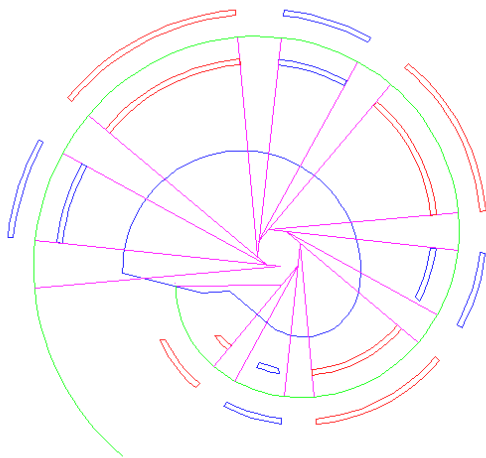


Figure 1: Reference trajectory and Dee and dummy Dee structure.

The structure model is then imported in OPERA environment and the electric field maps, necessary for

trajectory calculations, are computed. The magnetic field map is instead obtained from the magnet model simulated by OPERA code. The particle trajectories are calculated by a code in MATLAB environment, which evaluates the beam dynamics integrating the Lorentz's equation using the cartesian coordinates and time as independent variable of integration. The starting conditions are the position and the velocity of the particle at the spiral inflector exit.

Table 1: Central region parameters.

Parameter	Value	Parameter	Value
B_0	3.18 T	E_{inj}	25 keV / A
Gap_{infl}	6 mm	Gap_r	8 mm
ΔV_{infl}	14 KV	V_{gap}	70 KV
E_{infl}	23 KV / cm	E_{gap}	90 KV / cm

In order to optimize the energy gain and the beam centering, we selected a suitable phase range; we can also modify the first channel shape and position. The beam trajectories achieved along the first 3 turns for 3 particles with different phase values are shown in Figs [2, 3, 4].

The results here shown are not satisfactory yet, but we believe that, with further tentative, we'll be able to reach an average off-centering error near 2 mm. Then it will be necessary to introduce a first harmonic bump at the radii where the $v_r = 1$ to centre the beam. Our goal is to center the orbit in the first 20 turns.

Vertical focusing analysis is still in progress and results are not ready yet.

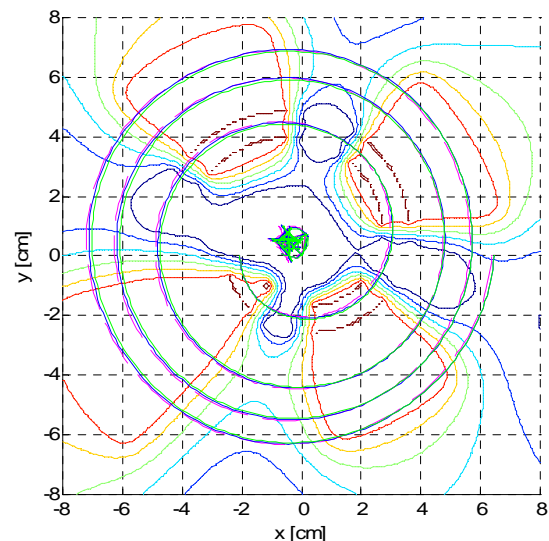


Figure 2: Trajectories of three particles with phase value in the range $220^\circ - 240^\circ$.

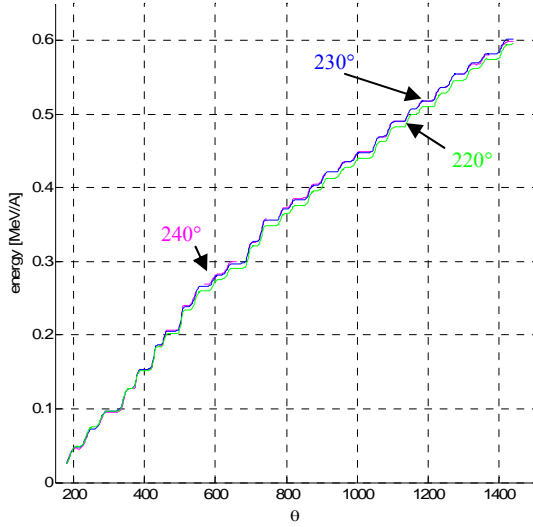


Figure 3: Energy gain of three particles with different phase.

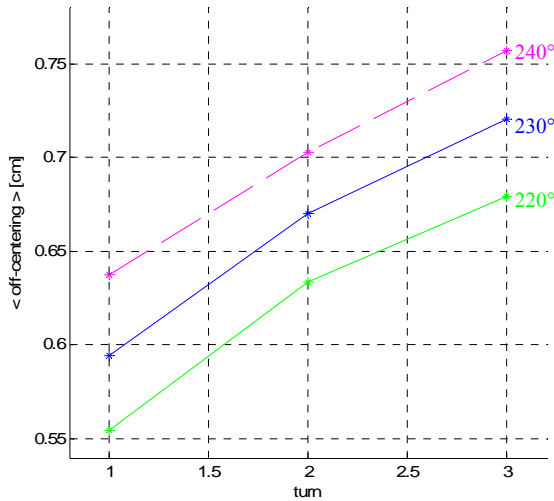


Figure 4: Mean beam centering for each turns.

STATIC ORBIT STUDY

In order to check the cyclotron magnetic field properties, we are developing some new programs for the static and equilibrium orbit study in MATLAB and Simulink environment.

The program uses the equations of the motion of a charged particle in a static magnetic field, obtained by Hagerdoorn and Verster studies [2]. A right-handed system of polar coordinates (θ, r, z) with the origin in the cyclotron centre is used. The plane $z = 0$ is the median plane and the z -axis the symmetry axis of the cyclotron; the independent variable of motion is θ , the azimuthal position.

The magnetic field component B_z is introduced as a polar grid (r, θ) in the median plane. Despite the program tests were performed using a set of polar grid maps

achieved by OPERA code, it will be also possible to use a grid maps achieved by experimental measures on a real magnet.

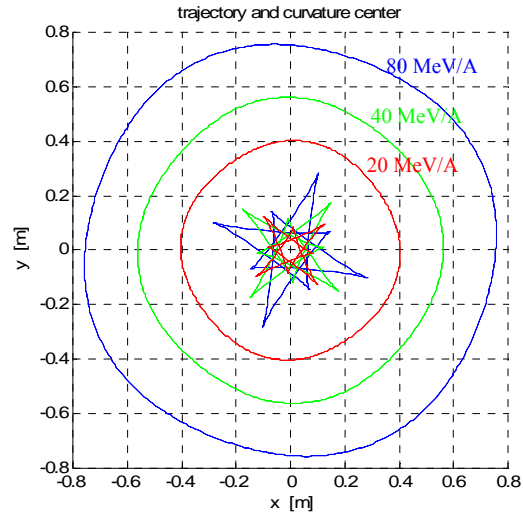


Figure 5: Equilibrium orbit for different energy values and their instantaneous curvature center.

During the calculation, the Simulink program computes the B_z component values with the cubic interpolation method from the (r, θ) grid, while the B_θ and B_r component values are calculated as B_z functions, by a double three point Lagrange interpolation of the map values. We have selected a Simulink integration method that is based on an explicit Runge – Kutta formula (Dormand – Prince pair).

We have developed a MATLAB algorithm based on Gordon's method [3] to find the equilibrium orbit condition for a fixed energy value [Fig. 6].

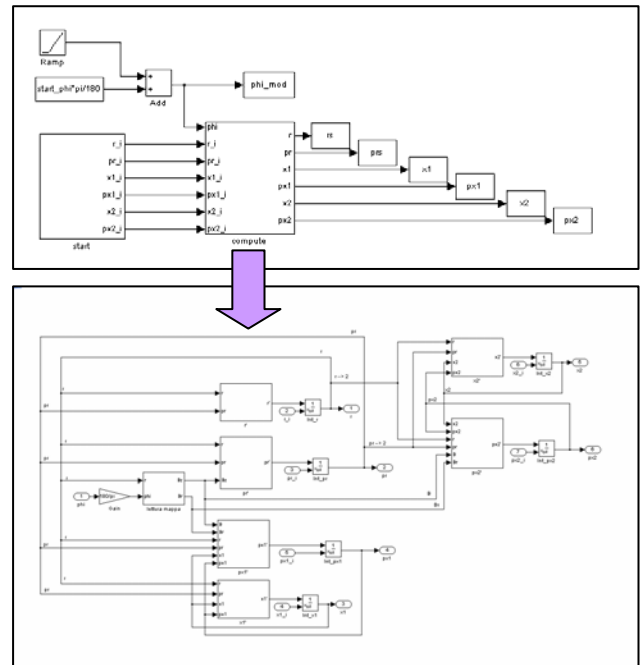


Figure 6: Simulink model for equilibrium orbit computing.

We studied a “quasi-equilibrium orbit” in a median plane sector that differs from the true equilibrium orbit only in first-order effects: an iteration procedure is repeated until a satisfactory value of (r_o, p_{r0}) is found.

The algorithm includes the controls on the execution: if the procedure does not converge to the fixed value of ϵ , the program is stopped and it displays the best found solution; thus, the user may employ this condition in a new run.

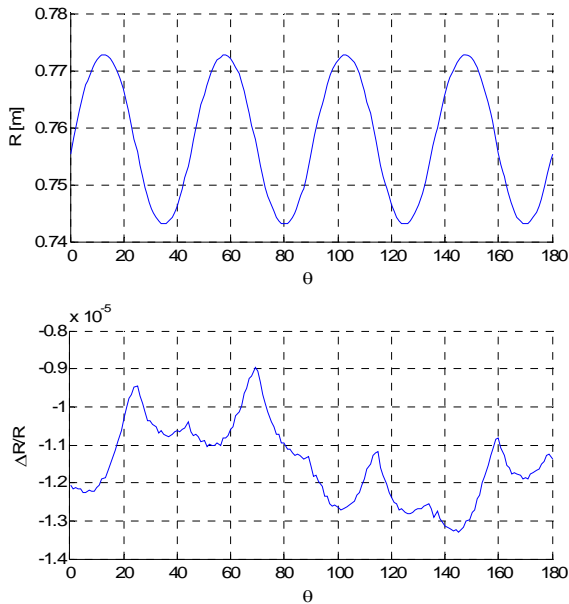


Figure 7: MATLAB vs. Z3CYCLONE: R coordinate for a static orbit and relative error on this value.

Our results were compared with the trajectories obtained from the code Z3CYCLONE; a good matching of the results was achieved [Figs. 7, 8].

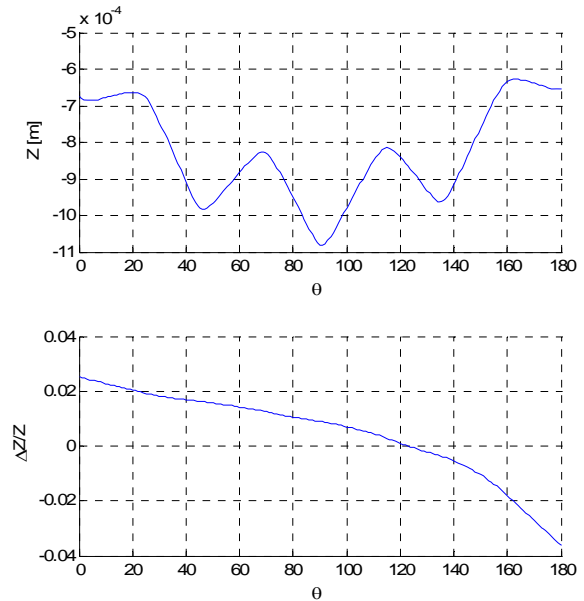


Figure 8: MATLAB vs. Z3CYCLONE: Z coordinate for a static orbit and relative error on this value.

REFERENCES

- [1] Toprek, NIM A 480 (2002) 379-386
- [2] H. L. Hagedoorn and N. F. Verster, NIM **18-19**, 201 (1962)
- [3] M. M. Gordon, *Particle Accelerators*, **16**, 39 (1984).