MAGNET OPTIMIZATION AND BEAM DYNAMIC CALCULATION OF THE 18 MeV CYCLOTRON BY TOSCA AND CYCLONE CODES

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Abstract

Designing and manufacturing of the 18 MeV cyclotron has been started for producing H^- for applications in Positron Emission Tomography (PET) radioisotopes at Amirkabir University Of Technology. Up to this point, there were 2 steps in magnet design: Initial design and optimization processes. The AVF structure with hill and valley was selected for getting strong axial focusing in magnet design and achieving up to 18 MeV energy for the particle. After finishing the initial design, optimization process in magnet design was started for achieving the best coincidence in magnetic field.

Checking the beam dynamic of the particle is one of the most important and necessary steps after magnet simulation. The phenomenon which confirms simulated magnet validity is obtaining reasonable particle trajectory. This paper focused on the optimization process in magnet design and simulation of the beam dynamic. Some results which ensure a particle can be accelerated up to 18 MeV energy, are presented. All magnetic field calculation in whole magnet was calculated by OPERA-3D (TOSCA) code. Also beam dynamic analysis by applying magnetic field data from the magnet simulation was done in CYCLONE code.

INTRODUCTION

The 18 MeV cyclotron magnet was designed with CST code and the STP file was uploaded in TOSCA code [1]. So all magnet calculations were done in TOSC code. The material of the magnet was considered steel-1010. The magnetic field curve versus radius before applying optimization process is shown in Fig. 1.

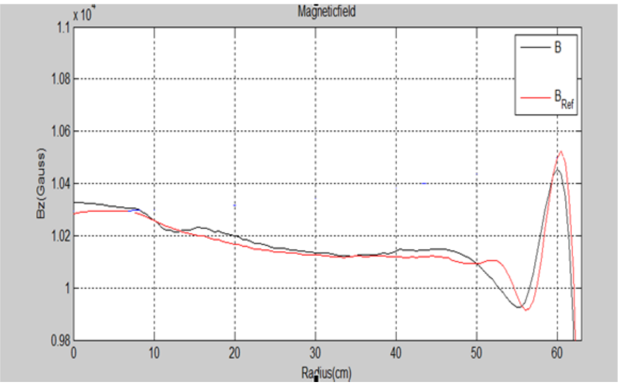

Figure 1: Average magnetic field versus radius before optimization process.

As shown in Fig. 1, B_{ref} (red curve) is the ideal magnetic field and the black one is the simulated magnetic field. Before applying the optimization method, there is not acceptable coincidence between two curves. So optimization process was started.

OPTIMIZATION METHODS

In magnet design, there are some methods which can be used for achieving best results. The methods which were used in optimization process are changing ampere-turn up to 58000, decreasing the gap between poles as a function of radius and shimming of pole edges [2].

Shimming of Pole Edges

At first, in initial design, horizontal shimming was used. In this way achievement to best result in magnetic field was difficult. So in the optimization process shimming of pole edges was changed to vertical form. In vertical shape, some of the pole points were selected and their heights were changed. Also triangle magnet shapes were added the end of the poles for increasing magnetic field at the end of the curve.

Figure 2 shows all used shimming methods in magnet design.

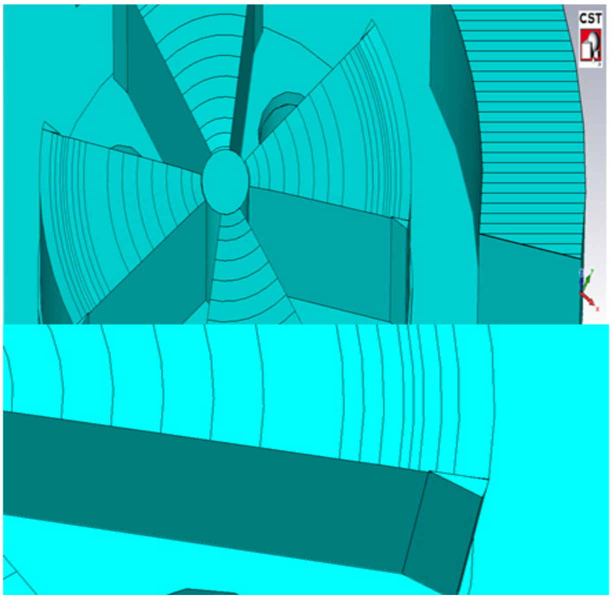

Figure 2: Shimming of pole edges.

AVERAGE MAGNETIC FIELD

After the using upper methods several times, the curve of magnetic filed versus radius was achieved same as the Fig. 3.

As shown, there is a reasonable coincidence between the ideal magnetic field and simulated value. Also, there is a magnetic filed initial increment at the fist of the curve, because that is necessary for vertical focusing on particle motion [3].

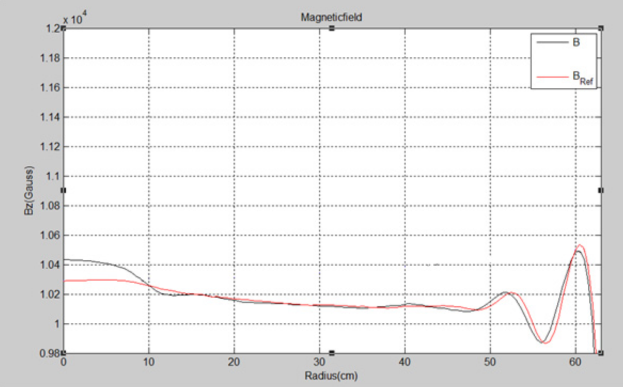

Figure 3: Average magnetic field versus radius after optimization process.

CHECKING THE MAGNETIC FIELD IN MIDDLE PLANE

After magnet simulation, some results should be checked. One of them is the contribution of magnetic field in middle plane. Maximum magnetic field in middle plane, where particle accelerates on it should not be more than saturation point of the magnet material. Figure 4 shows the magnetic field on middle plane.

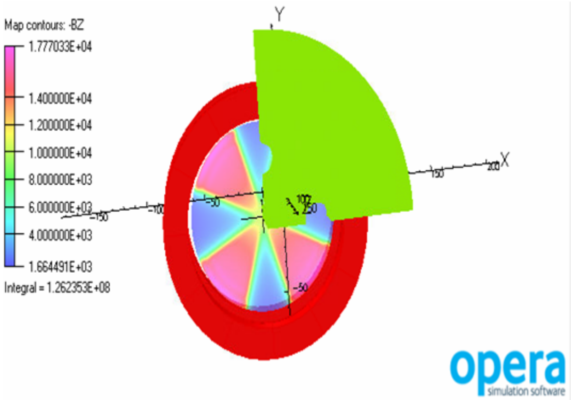

Figure 4: Magnetic field on middle plane.

As shown in Fig. 4, maximum magnetic field on middle plane is 1.77 Tesla is less than the saturation point of the magnet material (1.85 Tesla).

BETATRON OSCILLATIONS

In cyclotron motion (special in final orbits) some oscillations in vertical and horizontal direction occur. These are Betatron oscillations. Because of particle motion sensitivity in final tracks, all these oscillations should be checked. Betatron oscillations factors in tow direction are achieved by following equations:

$$\upsilon_z^{\,2} = 1 - \gamma^2 + \frac{N^2}{N^2 - 1} F \qquad (1)$$

$$\upsilon_r^{\,2} = \gamma^2 + \frac{3N^2}{(N^2 - 1)\times(N^2 - 4)} F \qquad (2)$$

For increasing particle stability in cyclotron motion, vertical oscillation factor should not be negative and the horizontal (or radial) value should not be less than one.

Figure 5 shows the calculated Betatron oscillation factors, As shown, they are in an acceptable range [4].

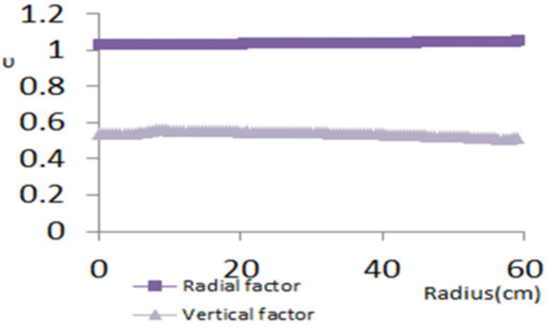

Figure 5: Betatron oscillation factors.

Finally the magnet optimization process was completed and a magnet was designed for 18 MeV energy with properties which are presented in Table 1.

Table 1: Designed Magnet Properties

Parameter	Value
Total radius	122 cm
Total height	129 cm
RF frequency	64.3 MHz
Hill angle	46
Valley angle	44
Pole gap	3.2 -6.68 cm
Coil dimensions	20 *22 cm
Number of amp-Turn	58000

BEAM DYNAMIC CALCULATION

After magnet simulation, the initial beam dynamic calculation was started until ensures that particle can accelerate up to 18MeV energy by magnetic field of the magnet. So for beam dynamic calculation, all magnetic field data from TOSCA code imported to CYCLONE code [5]. Then by changing the initial condition of particle same as Teta, energy, position, phase, the reasonable results were achieved.

Figure 6 shows the horizontal motion of particle in the middle plane of the cyclotron.

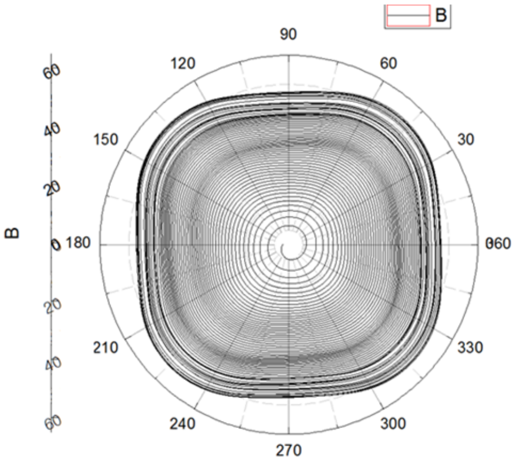

Figure 6: Horizontal motion of particle in middle plane.

As shown, a particle can accelerate in acceptable trajectory in the middle plane of the cyclotron with initial phase 38.027, initial energy 0.020 MeV and initial Teta 92.

Also, kinetic energy curve versus the number of turns are shown in Fig. 7.

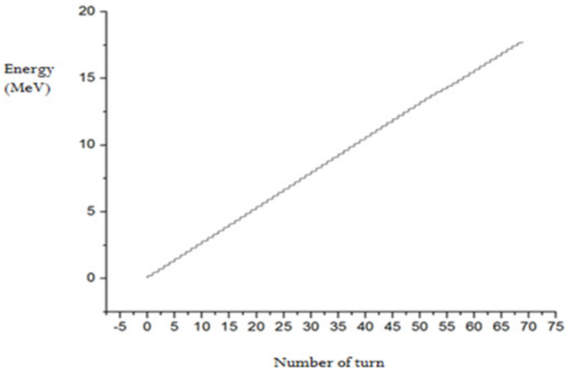

Figure 7: Kinetic energy versus number of turns.

As shown in Fig. 7, a particle can get 18 MeV energy in 70 turns.

CONCLUSION

Magnet optimization process and initial beam dynamic calculation of the 18 MeV cyclotron were presented. About magnet design, detail changes of magnet designing same as shimming was explained. The results of magnet design include magnetic field curve, contribution of magnetic field on middle plane and Betatron oscillations were checked. Then, with importing the magnetic field data from TOSCA code to CYCLONE some beam dynamic calculations were done and particle trajectory and kinetic energy were checked.

In future, by designing central region of 18 MeV cyclotron, beam dynamic calculations and results will be improved.

REFERENCES

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