

DESIGN AND SIMULATION OF 18 MeV CYCLOTRON MAGNET BY TOSCA CODE

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Abstract

The 18MeV cyclotron magnet was designed for medical applications at Amirkabir University of Technology. In magnet simulation all other subsystems should be considered, because all of them are related with magnet. Designed magnet with 4 hills and valleys has AVF structure. The TOSCA (Opera-3D) code was used for simulation and analysis. Designing process summarize in tow steps: At first all theoretical calculation of magnetic field according to radius were done and it's curve which is named theoretical curve was plotted. In next step simulation in TOSCA code was done with a simple model of magnet and optimization process began until when the curve of the simulation result coincided with the theoretical curve. The result showed that at most radius, the isochronous magnetic field difference between simulated values and calculation is less than 10 Gauss, so designed magnet is optimized. Also the particle trajectories were illustrated. According to the results, work points of the cyclotron are far from the resonances region. With considering reliable mesh the accuracy of simulation result is sufficient high.

INTRODUCTION

According to various applications of cyclotrons in the world is increasing, research, study and manufacturing about cyclotrons is considered in the world. Magnet is one of the most important components of cyclotron that stimulates particle in spiral path until particle achieve to particular energy. Magnet design is very important in cyclotron design and is an iterative process. The structure of 18 MeV cyclotron magnet is Azimuthally Variable Field (AVF). Also for an ideal design all other subsystems in the cyclotron should be considered. Three goals are followed in this paper: first procedure of achievement to isochronous magnetic field, second working points of the cyclotron and the resonance regions are checked and at the end, dynamic of particle's closed orbits are presented. Also magnetic field in middle plane of the magnet and calculation of magnet weight are mentioned.

BASIC THEORETICAL CALCULATIONS

There are some parameters which should be estimated and calculated before the basic calculations. At first value of RF frequency should be estimated for primary calculations. After accurate studying 64.3 MHz was selected for RF frequency.

With considering RF frequency, magnetic field relation according to radius is [1]:

$$B_{iso} = \frac{B_0}{\sqrt{1 - \left(\frac{300ZB_0r}{E_0}\right)^2}}$$

Figure 1 shows isochronous magnetic field according to radius diagram. This is theoretical diagram.

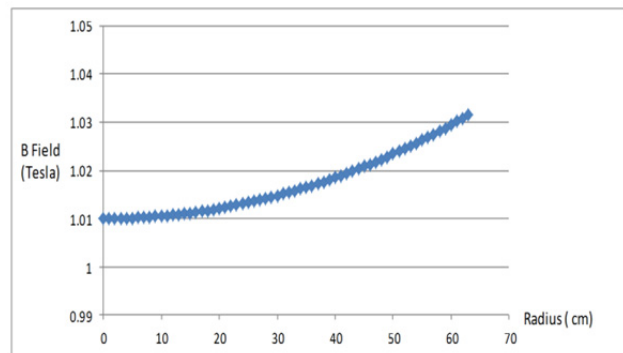


Figure 1: Isochronous magnetic field according to radius.

With using of cyclotron important equations, the relation between kinetic energy and radius is followed as [1]:

$$T(r) = \frac{938.27}{\sqrt{1 - 0.0000104 \times r^2}} - 938.27$$

Figure 2 shows kinetic energy of particle according to radius diagram that suggests existence of particle in various radiuses with different energy [2].

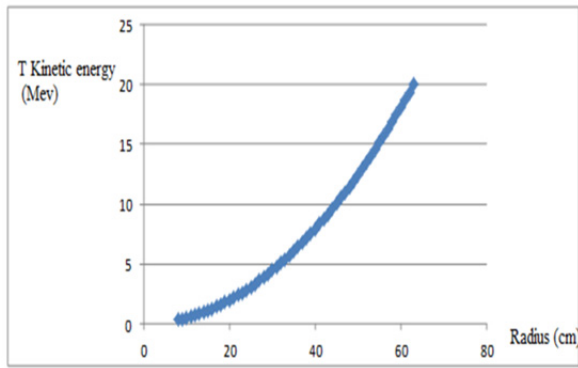


Figure 2: Kinetic energy of particle versus radius.

Then magnet simulation was begun with simple model of magnet. Optimization process continued until that magnetic field according to radius diagram achieved from the simulation result coincided with theoretical diagram. For achieving to best coincidence, gap between poles was selected 3.66 up to 5.99 centimeter.

Then estimation of ampere-turn should be done with Ampere law [1], so 28Ka is selected for more coincidence between theoretical magnetic field curve and simulation curve. The coils are producer of magnetic field in the magnet.

All important specification of the designed magnet structure is shown in Table 1 and the whole structure is shown in Figure 3.

Table 1: Main Characteristics of the RF System

Parameter	Value
Total radius	120 cm
Pole radius	63 cm
Number of sector	4
Hill angle	46
Valley angle	44
Gap between poles	3.66-5.72 cm
Total height	116 cm

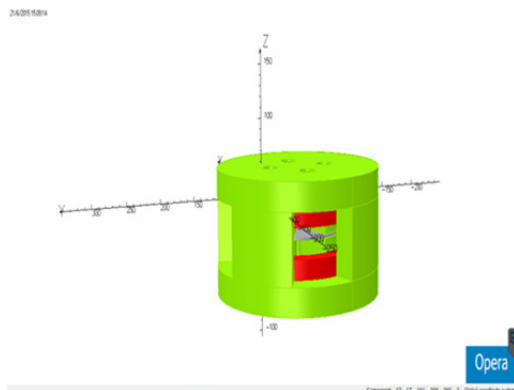


Figure 3: Overview of designed magnet in TOSCA code.

POLE RADIUS CALCULATION

All calculations of magnet design begin with magnetic rigidity relation from the following equation [3]:

$$B_{iso} \times R = \frac{\sqrt{T^2 + 2TE}}{300Z}$$

By using this equation and placement kinetic energy 18MeV, extraction radius is obtained 59 cm and with considering extraction element, pole radius increases to 63 centimeter.

SHIMMING OF POLE EDGE

For improvement of magnetic field process and approaching to theoretical state, shimming of pole edge was used. In design, same as the Figure 4, four triangle pieces with 10 angle was put in end of each pole. This design caused that magnetic field process in final positions was improved [4].

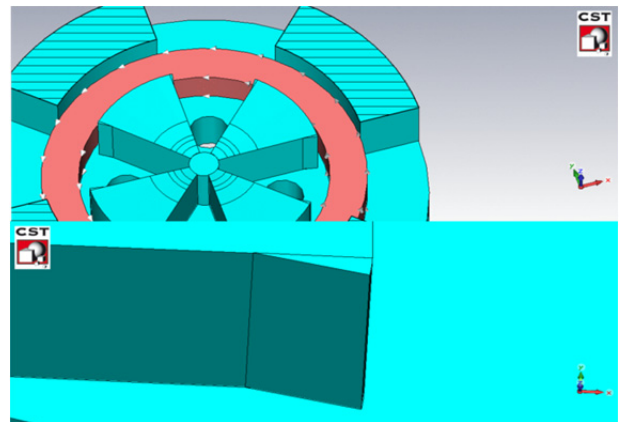


Figure 4: Shimming of pole edges in designed magnet.

SIMULATION RESULT

After early estimations and calculations simulation results are presented.

MAGNETIC FIELD DIAGRAM

All magnetic field calculations according to radius were done and its curve was plotted which is called theoretical curve. The final isochronous magnetic field curve is shown in Figure 5. As it is shown suitable coincidence is established between two curves in small scale.

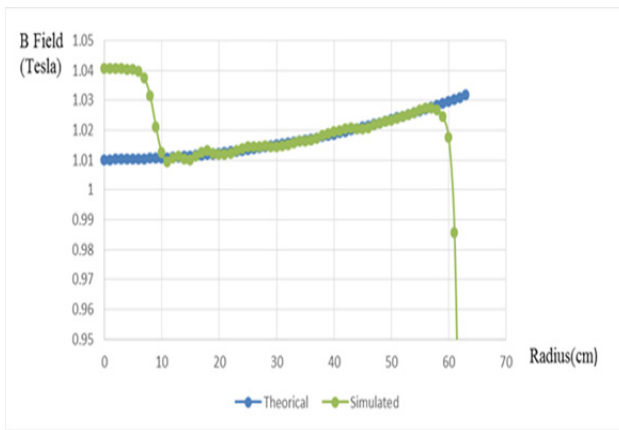


Figure 5: Isochronous magnetic field versus radius.

MAGNETIC FIELD IN MIDDLE PLANE

The magnetic field in middle plane (where particle orbits on it) is one of the most important parameters which should be checked after each simulation [5].

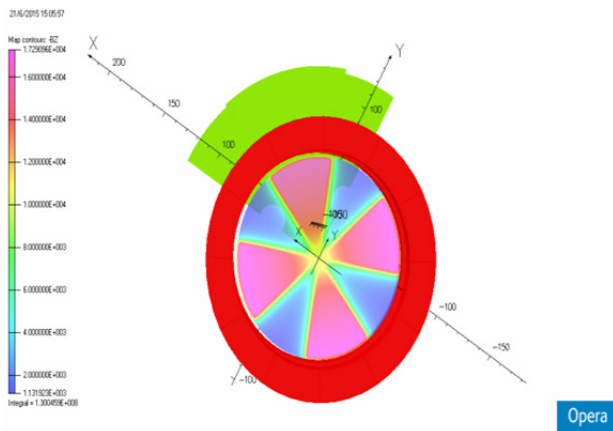


Figure 6: Distribution of magnetic field in middle plane.

As it is shown in Figure 6 maximum magnetic field in this plane is 1.72 Tesla that is less than saturated point of magnet material (AISI 10-10) 1.85Tesla.

MAGNETIC FIELD ERROR

The calculation of difference between tow curves in Figure 5 is magnetic field error in final designed magnet. This error is shown obviously in Figure 7 in small scale.

In ideal state theoretically, this difference should be about zero. But in simulation this value should be about 10^{-4} , as it is shown in Figure 7, magnetic field error in final design is less than 10 Gauss in more radiuses [4].

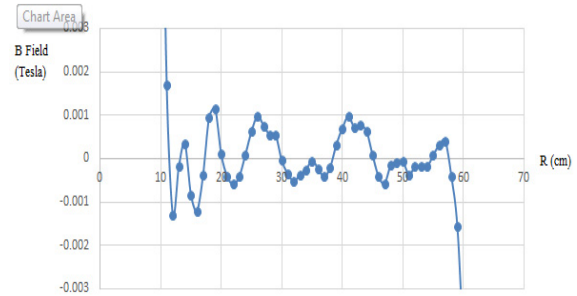


Figure 7: Magnetic field error.

BETATRON OSCILLATIONS

In particle motion at cyclotron, especially in final orbits, particle oscillates in vertical and radial exit. These are Betatron oscillations. From the following equations betatron oscillations factor obtained in each two directions [6]:

$$v_z = 1 - \gamma^2 + \frac{N^2}{N^2 - 1} F$$

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

For more particle stability, vertical oscillations factor should be positive and radial oscillations factor should be more than one. As it is shown in Figure 8 in this designed magnet, these limits are respected.

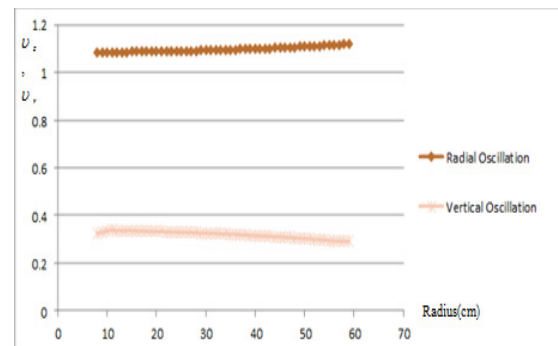


Figure 8: Betatron oscillations.

WORKING POINTS AND RESONANCE REGIONS

During cyclotron motion maybe some perturbations enter to particle. If frequency of these perturbations is same as particle revolution frequency, resonance will be happen. All resonances are destructive and destroy the particles. So working points of the cyclotron should be sufficient far from the resonance regions [7].

At first by using 4 and 5 equations, working points of the cyclotron are obtained, then with using following

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equation that presents all vertical and horizontal oscillations, all resonance lines up to 3rd order

($|L| + |K| \leq 3$) were plotted, Figure 9 shows coincidence between these two results [8].

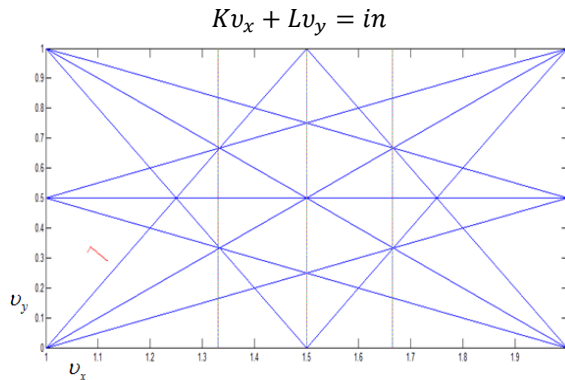


Figure 9: Resonance regions and working points.

As it is shown working points of cyclotron (red curve) are sufficient far from the resonance regions (blue lines).

CHECKING DYNAMIC OF CLOSED ORBITS OF PARTICLE MOTION

In TOSCA software can achieve to best particle tracks in various positions. Figure 10 shows accurate particle tracks in designed magnet [9].

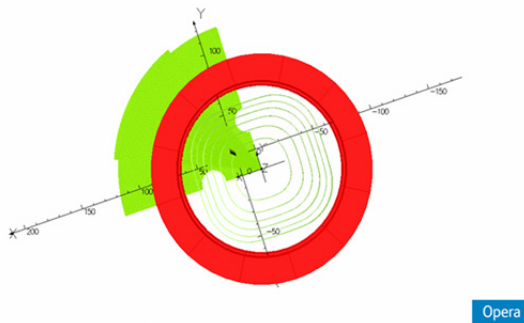


Figure 10: Tracks of particle.

Also in Table 2 energies and positions of particle in different radius is presented.

Table 2: Energies and Radiuses of Particle

Energy(MeV)	Radius(cm)
3	23
6	32
9	38.5
12	44
15	49
18	53

CONCLUSIONS

Design and simulation of 18 MeV cyclotron magnet has been followed accurately in this poster. Primary design calculation, initial estimation and all magnet specification was presented. The achieved result of the magnet contains isochronous magnetic field diagram, magnetic field in middle plane and magnetic field error in small scale were presented. Also betatron oscillations and destructive resonance regions for more particle stability were checked. In addition, dynamic of closed orbits of particle motion during accelerating was studied. At the end, magnet weight was calculated. Mesh factor in running the software is sufficient small and reliable and ensure the result validity.

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