CGN Medical Technology (CGNMT)

Design and Analysis of the 230 MeV Cyclotron Magnet for the Proton Therapy System

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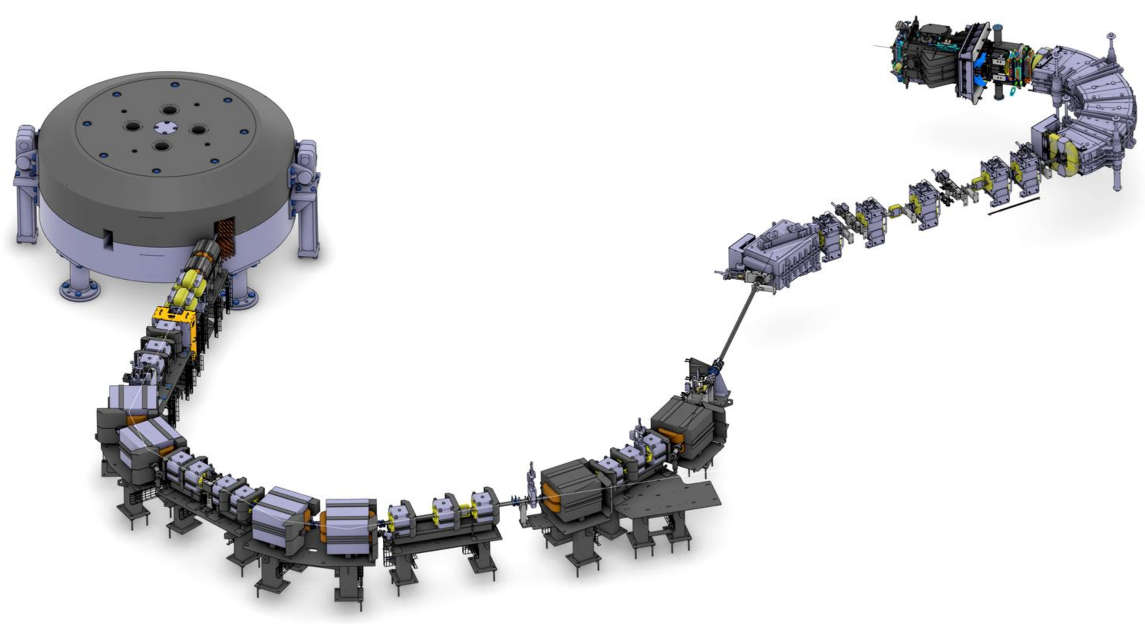
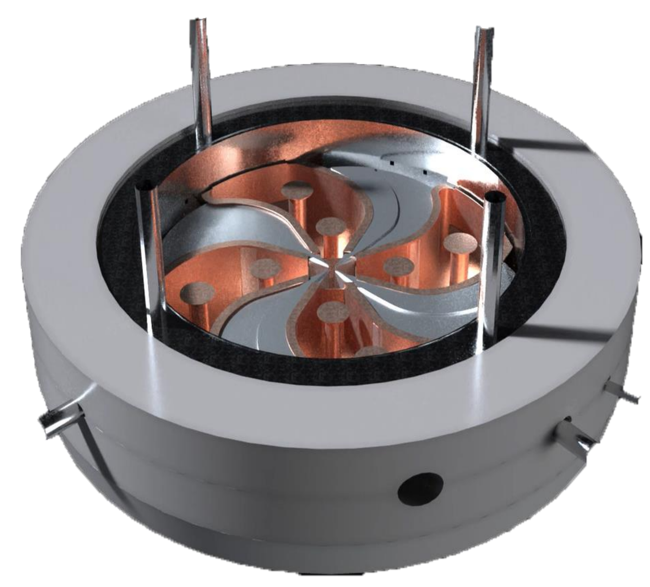
Abstract

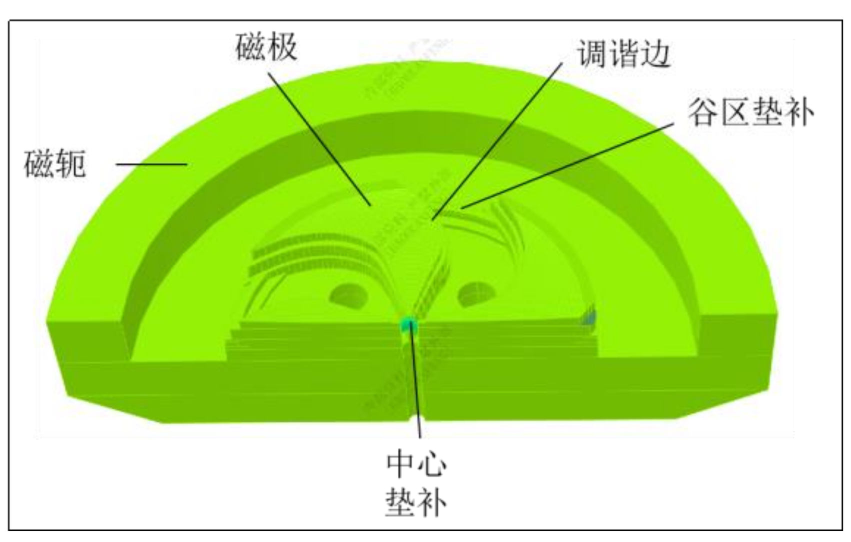
This paper introduces the design and analysis of 230 MeV cyclotron magnet of the proton therapy system. The magnet is an important part of the 230 MeV cyclotron, which can supply proton beam for the therapy terminal. The magnetic field calculation and modification has been done, and the isochronous error of the magnetic field is less than 2‰. Meanwhile, the thermal analysis of the coil has been calculated by the empirical formula.

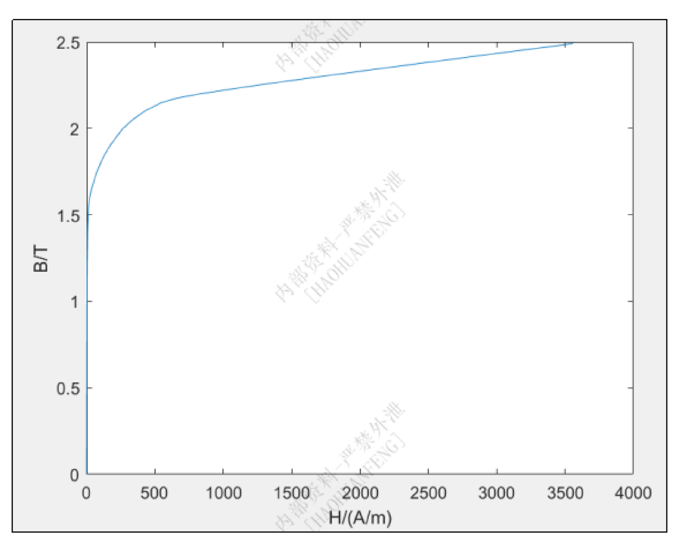
Introduction:

The proton cyclotron magnet is mainly composed of magnetic pole, magnetic yoke and pad. In order to achieve the design goal of 230MeV proton energy, a helical sector focusing structure, four blade poles and four harmonic acceleration are adopted. This kind of magnet structure is relatively simple and more compact. A replaceable tuning block is installed on the edge of the magnetic pole, and the isochronicity of the magnetic field can be adjusted by adjusting the tuning block size. In order to ensure isochronous acceleration conditions, the design goal is to have isochronous error less than 0.2‰.

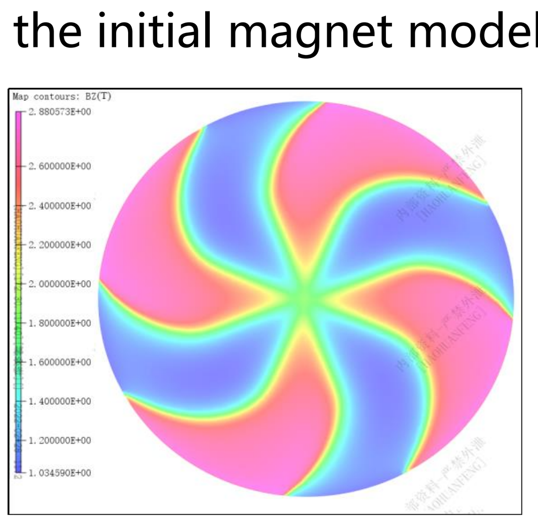


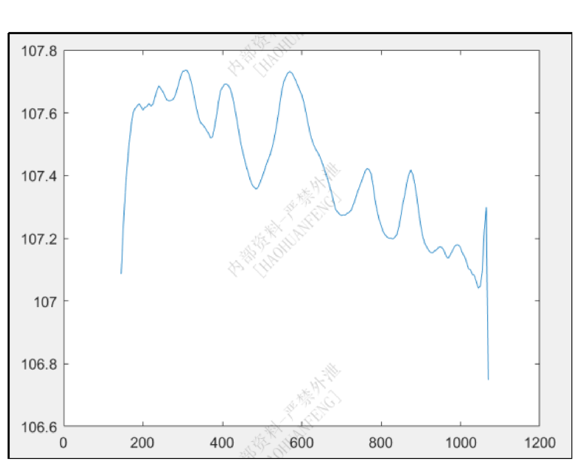


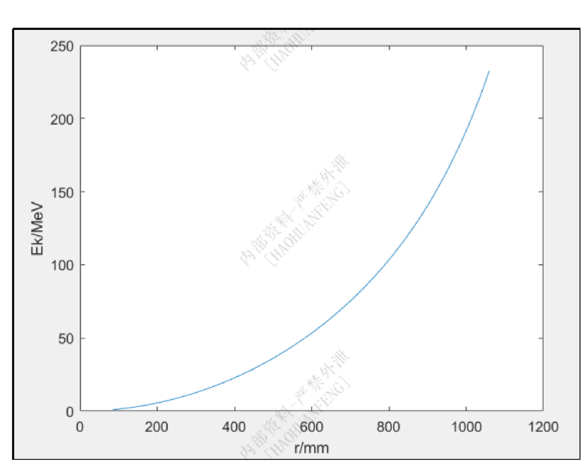




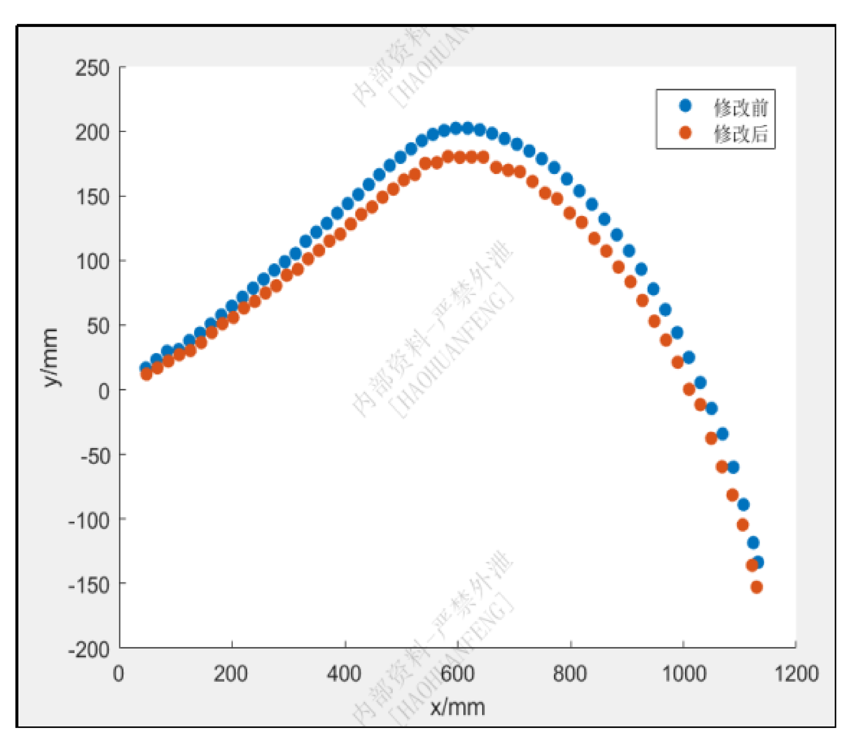
The main magnet of the accelerator was modeled with Opera3D. The yoke material was selected as low carbon steel. The magnetization curve was shown as the figure above. The acceleration frequency and energy curves of the initial model are shown respectively. The particle energy can meet the design requirements, indicating that the profile is basically correct. However, the acceleration frequency fluctuation is large in the initial model, which does not have the condition of isochronicity. Therefore, it is necessary to optimize the initial magnet model.

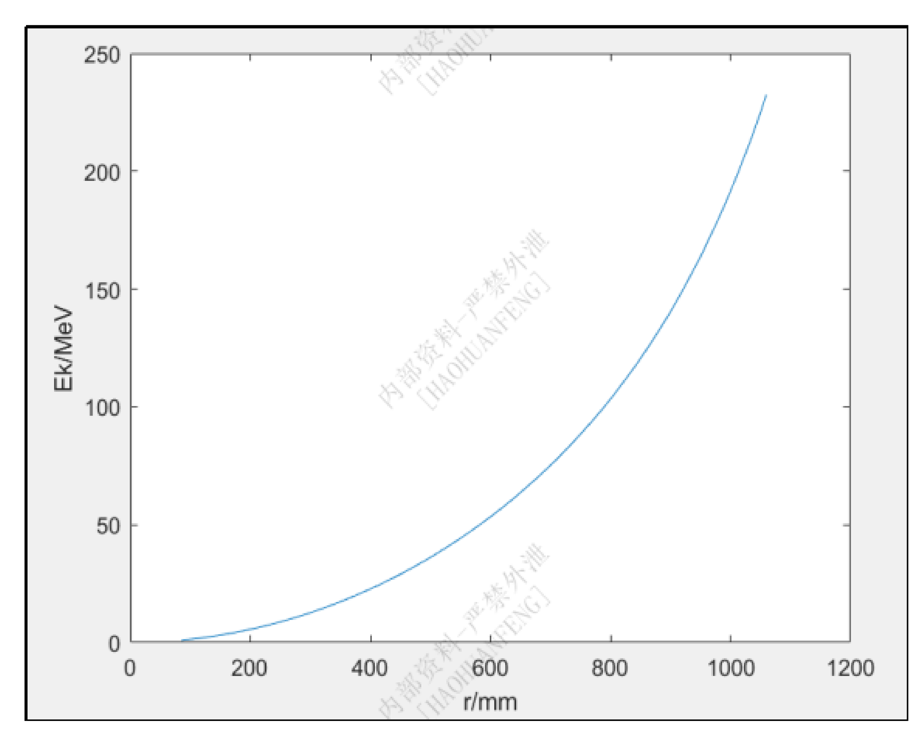






When the rf frequency is large, it indicates that the reference particle is ahead of the acceleration voltage. The cyclotron frequency of the particle will be reduced, through changing the magnetic field by adjusting the angle of the magnetic pole at the radius. Instead, it is necessary to increase the magnetic field, through increase the angle of the magnetic pole at this radius. The final optimized magnetic field has been shown below. At the radius of 1060 mm, the particle energy can reach 232MeV, which meets the design requirements.





The custom oxygen-free copper wire with inner circle and outer square is selected. The specification is 9.5*20.9*20.5mm. The total resistance of the coil is 298mΩ. There are 352 turns of single coil, inner diameter of 2360mm, outer diameter of 3340mm, height of 350mm.

Through the simulation results, the coil current density is 1.525A/mm², and the ampere-turns 261537.5 A. The coil current is about 743A, and the power is about 165kW.

It is generally believed that the inlet temperature of coil cooling water is about 20℃, and the outlet temperature is below 45℃.

The total water flow $q = \dfrac{P}{c_P \cdot \rho \cdot \Delta T}$ is 94 L/min. The calculated pressure loss of cooling water in the coil is 1.149 MPa.

The cooling system is set to cooling water pressure of 1.5 MPa , coil cooling flow of 99.2 L/min.

sectors	4
Sectors gap (min/max)	9.6/96 mm
Hill field(max)	2.9 T
Valley field	0.9 T
Average field at extraction	2.188 T
Average field at center	1.76 T
Power consumption (per coil)	110 kW
Weight (per coil)	10.4 t
Yoke weight	200 t

Conclusion

In this paper, the electromagnetic field analysis software Opera3D is used for modeling and analysis of the cyclotron magnet, and by comparing with isochronous field, the magnetic model is modified accordingly. Through the magnetic field calculation and modification, the isochronous error of particles is less than 2‰. By adding a permanent magnet in the center area, the magnetic field at a small radius has a negative gradient, providing an axial weak focusing force, so as to meet the axial stability condition. Finally, the ideal model of proton cyclotron magnet has been obtained. Meanwhile, the temperature rise and pressure drop of the coil have been calculated.