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THE BEAM DYNAMICS SIMULATION OF A VARIABLE ENERGY CYCLOTRON FOR ISOTOPE PRODUCTION

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Abstract

The isochronous cyclotron, CIMV16, has been designed by Hefei CAS Ion Medical and Technical Devices Co., Ltd, China (HFCIM) for widely used isotope production, which can extract proton with variable energy in range of 10~16 MeV. In this cyclotron, negative hydrogen ion will be accelerated to 10~16 MeV, and then stripped out two electrons to become proton to be extracted. We have performed beam tracking starting from the ion source to the extraction reference point, and optimized the position of the stripping target to make the beam of different energies converge at radius of 110 cm. The orbit centralization is optimized by the design of first harmonic, and the axial size of extraction beam is also optimized. All the results of beam dynamics simulations will be presented.

INTRODUCTION

Small cyclotrons for isotope production have developed greatly in past few years. According to the International Atomic Energy Agency (IEAE) official statistics, the energy distribution of low-level cyclotrons in China, the United States and Japan is mainly 10~18 MeV, and 75% of them are between 10~16 MeV. For cyclotrons with single energy extraction, it is difficult to meet the production of multiple isotopes at the same time. Therefore, if variable energy extraction can be realized in this energy range, it will certainly meet the demand of isotope production better. Based on this precondition, CIMV16 has been designed by HFCIM.

Referring to other medical isotope products of the same type, the CIMV16 adopts three Sector-shaped poles and use 3rd harmonic to accelerate. The parameters are shown in Table 1.

Table 1: Parameters of CIMV16

Parameter	Value
Accelerated particle	H^-
Central field	1.36 T
Max. averaged field	1.57 T
Outer radius of yoke	900 mm
RF frequency	70.8 MHz
Harmonic number	3
Energy	10~16 MeV
Beam Current	150 uA
Extraction mode	Stripping

SINGLE PARTICLE BEAM DYNAMICS SIMULATION

Based on the analysis of the equilibrium orbits, we finished the Single particle beam dynamics simulation. From the simulation results of single particles, we can see that particle can be accelerated to more than 16 MeV, and by adjusting the position of the stripping target, Proton with different energies in range of 10~16 MeV can be extracted, and we also make the beam converges at 110 cm after extracted by optimizing the position of the stripping target. The trajectories of different energy particle are shown in Fig. 1 and the positions of the stripping target corresponding to different energies are shown in Table 2.

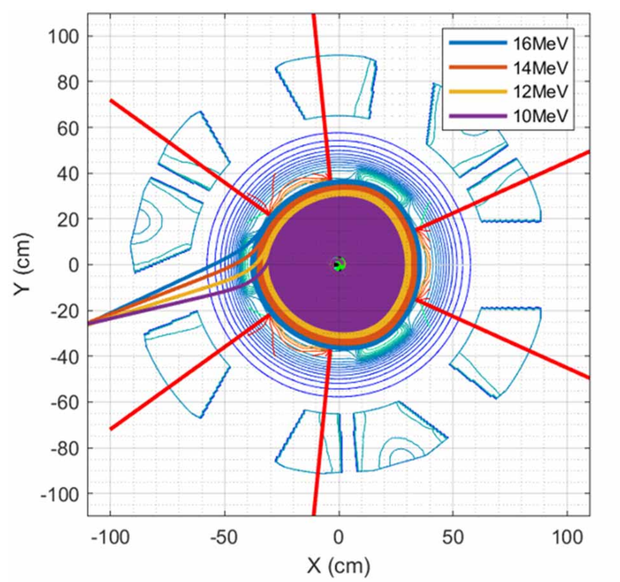

Figure 1: Trajectories of single particle with different energies.

Table 2: Position of Stripping Target

Energy (MeV)	Radius (cm)	Azimuth (deg)
16	30.0	170
14	34.5	164
12	32.5	158
10	37.0	153

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The integral phase motion of the 16 MeV extraction particle is shown in Fig. 2, we can see that the phase motion of the acceleration region is within plus or minus 10 degrees. The radius varies with the energy is shown in Fig. 3, we can see the radii of different energies from this figure. Through the above simulation results, we believe that the design of variable energy extraction in the energy range of 10~16 MeV and the isochronicity of magnetic fields have been achieved.

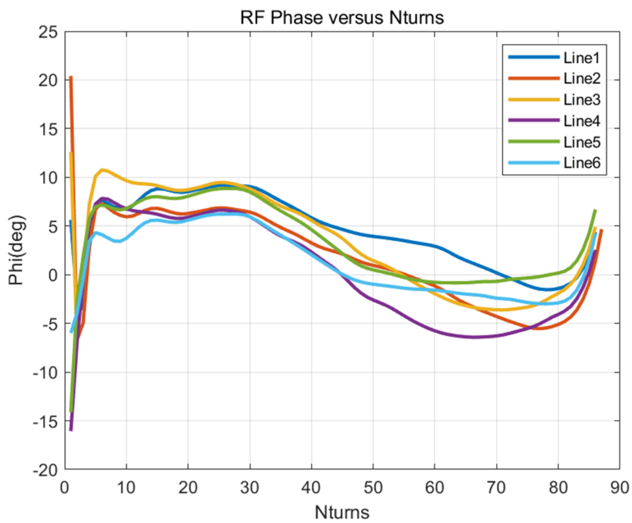

Figure 2: phase motion of the 16 MeV extraction particle.

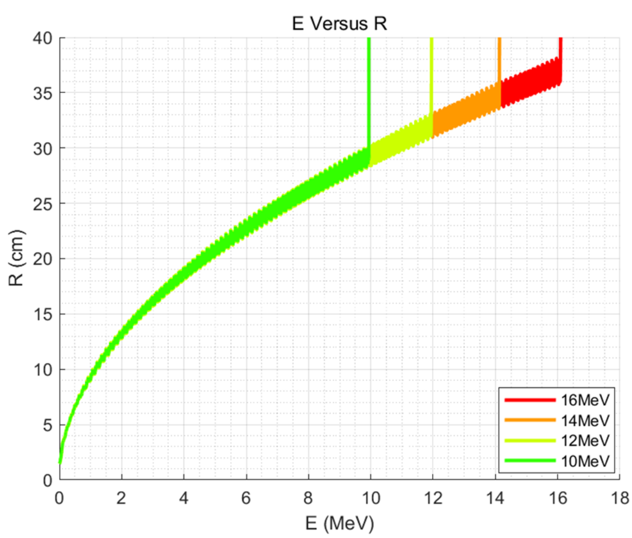

Figure 3: radius varies with the energy.

MULTI-PARTICLE BEAM DYNAMICS SIMULATION

Multi-particle beam dynamics have been down by the beam dynamics code cyclone and the self-develop code (CYCMOT). 5000 particles have been used. The parameters of initial particles are shown in Table 3.

Table 3: Initial Particles Parameters

Parameter		Value
radial	R	Rc±0.25 mm
	Pr	Prc ± 15°
axial	Z	0 ±2mm
	Pz	0 ± 5 °
Phase		-90°~0°

The particles with different initial phase have been marked to count the phase width that can be extracted. The radial and axial oscillations are also be calculated. To optimize the Ar of the beam, we design the first harmonic in the central region by magnetic poles.

The result of the phase width is shown in Fig. 4, and we can see that the phase width is about 70 deg.

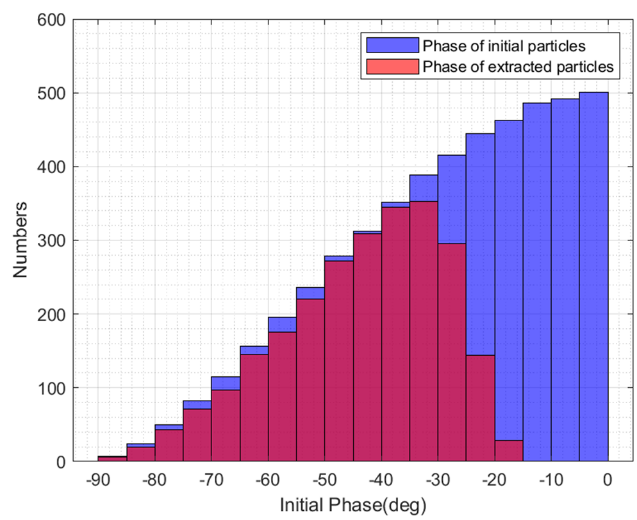

Figure 4: initial phase and extracted particles phase.

We have tried series first harmonic to optimize the radial oscillation and finally we choose the first harmonic with 100 Gs amplitude at radius of 2.5 cm, and the phase is about 110 deg. The distribution of first harmonic is shown in Fig. 5.

After we add this first harmonic the Ar of the beam is less than 3 mm and the Ac of the beam is less than 1 mm. the result is shown in Fig. 6.

We also optimized the axial size of the beam. In this optimization process, we use a brick in central region to block the particles with large axial oscillation, and after series simulations we found that the length of brick should larger than 8 mm along radius. In this way, we controlled the axial size of the beam in central region in range of -5~5 mm. The result is shown in Fig. 7.

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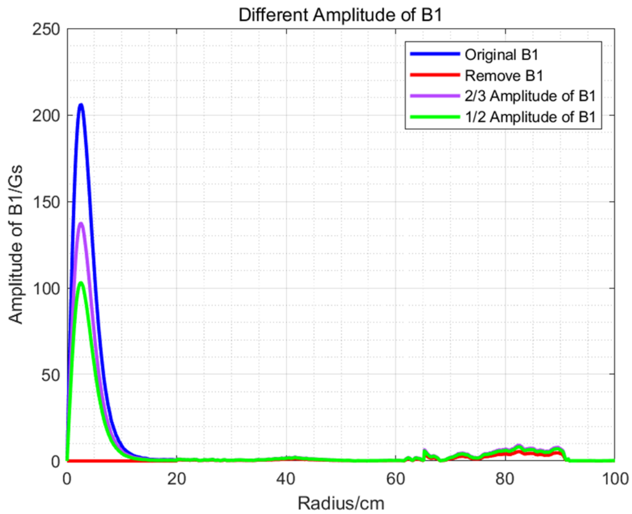

Figure 5: first harmonic distribution and optimization.

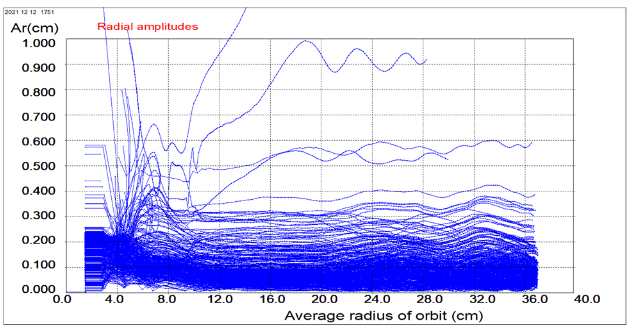

Figure 6: radial oscillations after optimization.

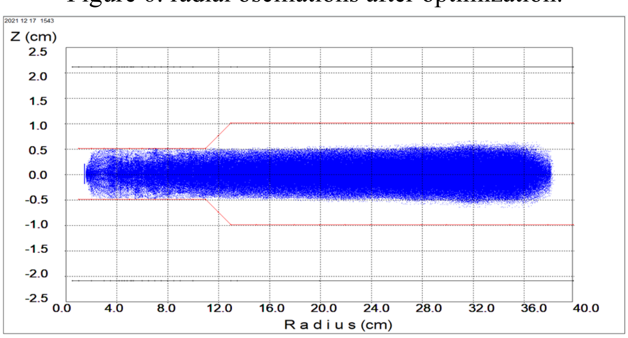

Figure 7: Axial oscillations after optimization.

There are 2525 particles from 5000 initial particles that can be accelerated to 16 MeV, it means that the transmission efficiency from ion source to stripping target is about 50.5%, a good transmission efficiency.

EXTRACTION

This cyclotron used stripping extraction method which can effectively increase the extraction efficiency. It should be noted that this method of extraction will cause the beam to have a large divergence due to the lack of focusing elements [1]. Based on this situation, we used axial brick to control the axial size of the beam, in addition, we also optimized the position of stripping target to make the beam of different energies converge at the same point which can make the further optimization easy.

The axial motion of beam after stripped before and after optimized are shown in Figs. 8 and 9.

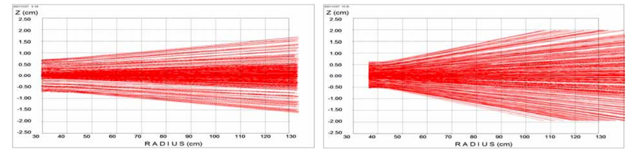

Figure 8: The axial motion of beam in energy of 10 MeV before optimized (left), and the axial motion of beam in energy of 16 MeV before optimized (right).

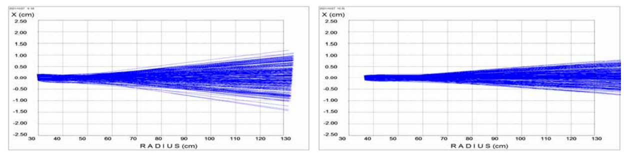

Figure 9: The axial motion of beam in energy of 10 MeV after optimized (left), and the axial motion of beam in energy of 16 MeV after optimized (right).

From the results, it can be seen that the axial size of the beam is controlled within 0.8 cm at reference point.

The extraction optimization result is shown in Fig. 10.

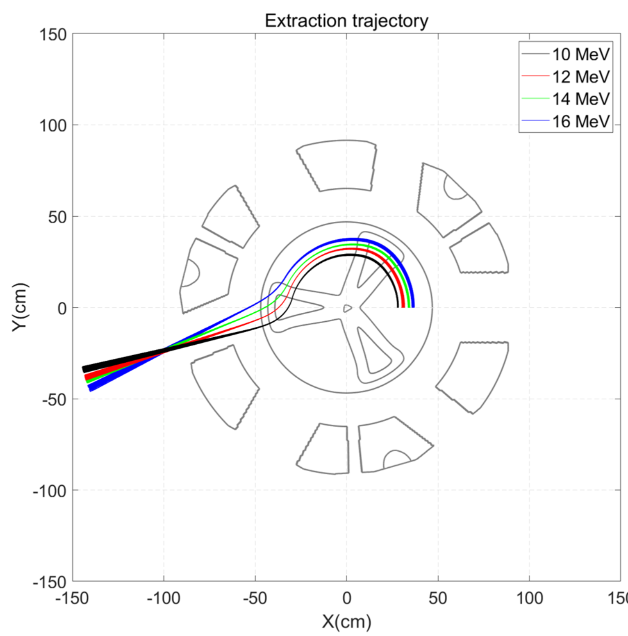

Figure 10: Extraction trajectories of different energies.

CONCLUSION

The beam dynamics analysis of the CIMV16 cyclotron have been finished from the ion source to exit of the cyclotron. The width of the phase is larger than 70 degrees and the beam transmission efficiency from the ion source to strip foil is larger than 50%. According to our simulations we can expect more than 45% beam transmission efficiency from the ion source to reference point [2].

The axial size of beam at reference point can be controlled smaller than 0.8 cm by using axial limit brick. The Ar can be controlled smaller than 3 mm by first harmonic in central region. And the different energy beam converges at reference point successfully.

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