BEAM EXTRACTION SYSTEM DESIGN FOR CYCIAE-14

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Abstract

A 14MeV medical cyclotron is under design and construction at CIAE (China Institute of Atomic Energy). H^- ion will be accelerated in this cyclotron and proton beam will be extracted by carbon strippers in dual opposite direction. Two stripping points are chosen in each extracting direction to extract proton beams to different targets to extend the use of the machine and the stripping points can be selected only by rotating the stripping foil. Two modes have been considered of the extraction system, one is designed to be installed on the wall of the vacuum chamber, the other is designed to be inserted vertically from the sector poles. Final choice will depend on the agility, the simpleness and the results of the experimentation. The angle between the stripper and the beam orbit is optimized to improve the extracted beam quality. Numerical simulation shows the two stripping points, the beam orbit and the beam characteristic at each extraction direction. The optimized azimuth of the stripper is also presented in this paper to show its influence for the beam quality. Based on the concept design, the mechanical design and the correlative experimentation have been done; the results are shown in the paper.

PACS: 29.20.HM CYCLOTRON;
Key words: cyclotron, proton beam, extraction system, stripping foil

INTRODUCTION

Since the incidence of cancer and cardiovascular disease is increasing, the domestic demand for PET cyclotrons in China is increasing rapidly. For productions of medical radioactive isotope, a compact cyclotron is under design and construction at CIAE. H^- ion is accelerated up to 14MeV in this machine. Except the radioactive isotopes usually produced by PET cyclotrons such as ^{18}F and ^{201}Tl, this cyclotron is also designed to produce the isotopes that usually produced by reactors such as ^{99}Tc, so the intensity of the extracted proton beam is up to 400 μA. In most PET cyclotrons, stripping method is used [1, 2] for high extraction efficiency. CYCIAE-14 [3] will use carbon foils to extract proton beam in dual opposite direction. In each extraction direction, two beams are extracted to extend the use of the machine, as shown in figuer 1: in primary design, the beam 2 is to hitting the liquid target directly for ^{18}F production, the beam 1 is to be sent to a beam line to hit the solid target to produce medical radioactive isotope such as ^{124}I and ^{201}Tl. Two stripping points in each extracted direction can be selected only by rotating the stripping foil to allot beam to different target or beam line easily.

For the cyclotrons whose extraction energy can be changed, the combination magnets are necessary in the extraction region. But for most PET cyclotrons with single extraction energy, there is no combination magnet, as shown in figure 1.

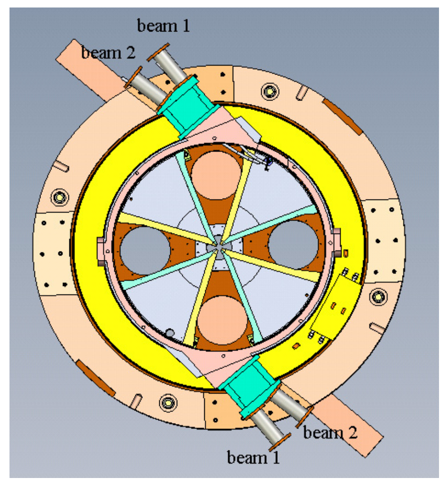

Fig.1 The extracted proton beams of CYCIAE-14

Two types of mechanical design for extraction system have been accomplished, one is designed to be installed transversely on the vacuum chamber and the other one is vertically from the sector poles, the design and the corresponding experimentation are also shown in this paper.

STRIPPING POINT AND THE BEAM DISTRIBUTION

Stripping Points on Each Direction

There are two stripping points in each extraction direction to allot proton beam to different targets, they can be calculated under the affirmatory magnetic field and target. Table 1 shows the radius and angles of two points in one direction, in which the point 1 is the right one shown in figure 1, they are calculated by using the code GOBLIN [4].

Table 1 Stripping points of CYCIAE-14

Points	Radius/ cm	Angle/ deg
1	45.69	57.09
2	45.22	61.38

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Beam Distribution

Beam distribution on the foil have been calculated by using the code COMA and shown in figure 2 (left pictures in figure 2), only the beam 1 has been selected as an example.

GOBLIN is a common particle tracking computer code, with the help of the TRIUMF scientists, CIAE had been extended the function of this code, new subroutine had been added to calcualte the transfer matrix from stripper to the combination magnet. The upgraded code had been used for extraction optics simulation of several cyclotrons in CIAE. CYCIAE-14 also use this upgraded code to calculate the extraction optics. With the affirmatory magnetic field, the transfer matrix including the dispersion forms the stripping foil to the outside of the return yoke (about 70 cm after stripping foil) had been obtained and shown in the next section. The particles distribution outside of the return yoke then can be obtained by matrices multiplication, also shown in the right pictures of figure 2. The horizontal beam dimension increased from 4 mm to about 10 mm without any focusing elements.

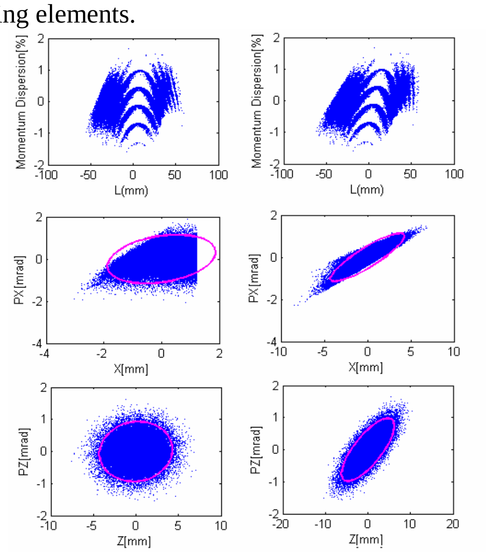


Fig.2 Beam distribution on the foil and out of the return yoke

TRANSFER MATRIX, DISPERSION AND THE BEAM CHARACTER IN EXTRACTION REGION

Transfer Matrix and Dispersion in Extraction Region

Through the fringe field of the main magnet, the transfer matrix with dispersion of the two extracted beams can be obtained [5]. Take the extracted beam 1 as an example, its transfer matrix is shown in table 2. The elements R_{16} and R_{26} in the matrix are the dispersion in mm/% and mrad/%, it is indicate that for the extracted beam 1, a momentum dispersion of 0.5% may bring a 1.36mm displacement of the beam in horizontal plane out of the return yoke, as shown in figure 2, form the foil to the outside of the return yoke, the beam distribution in horizontal plane is changing from 4 mm to almost 10 mm.

Table 2 the transfer matrix from stripping foil to the outside of the return yoke of beam 1

$$\begin{bmatrix} 0.1078 & 0.6350 & 0 & 0 & 0 & 2.7191 \\ -1.4257 & 0.8767 & 0 & 0 & 0 & 4.2401 \\ 0 & 0 & 1.0592 & 0.7240 & 0 & 0 \\ 0 & 0 & 0.1370 & 1.0377 & 0 & 0 \\ -0.4334 & -0.0310 & 0 & 0 & 1 & 6.8540 \\ 0 & 0 & 0 & 0 & 0 & 1 \end{bmatrix}$$

Beam Character

By using the code GOBLIN and COMA, the beam distribution on the foil and the transfer matrix along the extracted beam orbit can be obtained. Then the beams envelop and the emittance can be got by multiplying these matrices. The envelop from the foil to the target are shown in figure 4, and he figure 3 shows the transverse emittance, the emittance will increased a little in the horizontal plane because of the dispersion, and keeped constant in the vertical plane.

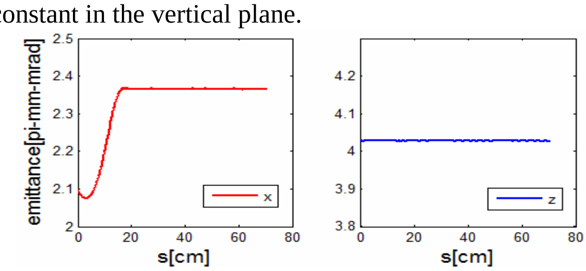


Fig.3 Emittance of the extracted beam

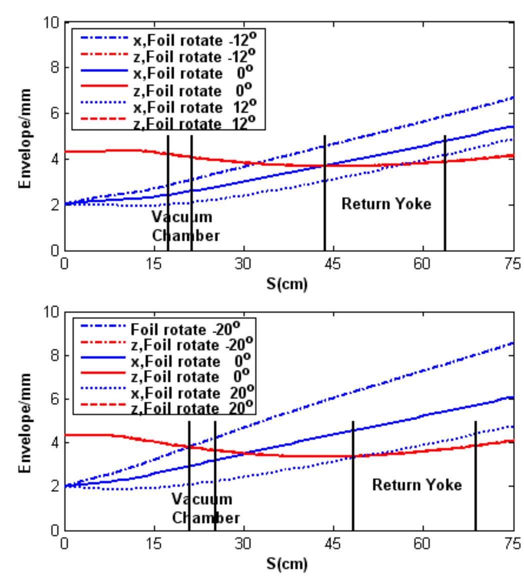


Fig.4 Beam envelope with and without foil rotate (upper:beam 1, nether: beam 2)

Usually the stripping foil is perpendicular to the beam orbit, when rotating the foil for a small angle, the extracted beam envelop will be changed in radial direction, just like the edge angle of a dipole magnet.

Numerical simulation shows that the horizontal envelop changes sensitively to the rotating angle, but the vertical envelop almost the same. Figure 4 shows the beam envelop with and without a rotating angle of the two extracted beam, from which we can see that the envelop in horizontal plane can be optimized by this angle. Beam 1 is transported to beam line and will be focused by quadrupoles out of the return yoke as soon as possible; beam 2 will hit the liquid target directly inside the return yoke. For this calculation, the initial emittance of the two beam are 4 π mm·mrad, usually the emittance of the injected beam is better than 4 π mm·mrad, so we can adjust the beam spot as Φ8mm, if various beam sizes are needed, then we can adjust the foil angle, as shoen in figure 4.

MECHANICAL DESIGN AND EXPERIMENTATION

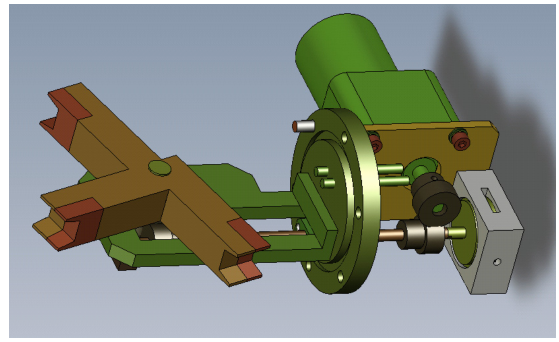
Two mechanical types of extraction system have been designed based on the optics simulation mentioned above. Figure 5 shows the two types, the upper one is designed to be installed transversely on the vacuum chamber; the nether one is vertically from the sector poles.

The transverse one which is installed on the vacuum cavity wall is drove by motor, the motor and the potentiometer used for feedback are put between the main coils, in where the magnetic field is about several hundreds Gauss. The experiment of the DC motor and the step motor working in the magnetic field had been carried out, the results shows that the DC motor can still work at the field of 2000 G normally, but when the field is above 620G, a 1.5 Nm step motor stop working.

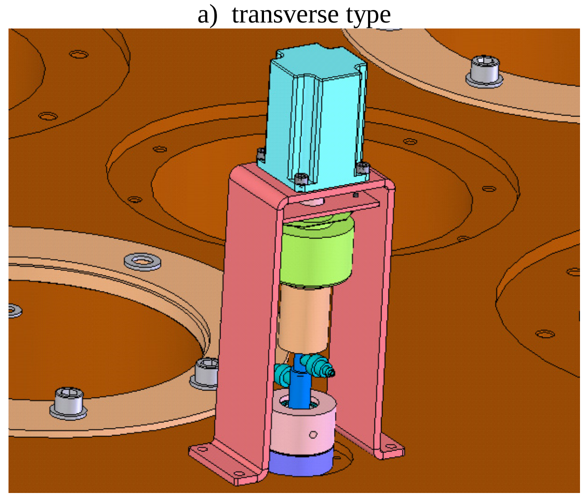
The advantages of the transverse one are: 1) the foil can be rotated to the stripping point easily only by using a motor; 2) no need to drill the pole, so the isochronous field would not be broken. The disadvantages are: 1) the potentiometer can't be installed directly on the rotating axes of the stripping foil, so the control precision can't be so high; 2) this configuration is hard to water-cooling.

The advantages of the vertical one are: 1) the foil can be rotated to the stripping point easily, too; 2) can be water cooled easily; 3) the potentiometer can be installed directly on the rotating axes of the stripping foil; 4) the motor and the potentiometer are out of the magnetic field and the radiant field. The disadvantages are: 1) needed to drill on the pole, which means to influence the isochronous field.

For CYCIAE-14, the extracted proton beam intensity is up to 400 μA, water-cooling for the extraction system is necessary, so the vertical type is selected as the final design. Now this system is under manufacturing based on the design above. But for those PET cyclotrons with low extraction intensity, the transverse one can be used too.



a) transverse type



b) vertical type

Fig.5 Mechanical design of extraction system for CYCIAE-14

CONCLUSION

The extraction system of a 14 MeV PET cyclotron have been designed and is under machining, the proton beam is extracted in dual opposite direction by using carbon foil. In each extraction direction, two beams are extracted only by rotating the foil to allot beam to different target or beam line. The stripping points, particles distribution, beam envelop and transfer matrix are calculated. Two types of mechanical design are carried out and the vertical one is selected as the final design. Now this system is under manufacturing based on these design.

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