PHYSICS DESIGN OF CYCIAE-70 EXTRACTION AND BEAMLINE SYSTEM

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Abstract

A driver with beam power of 50KW (70 MeV, 0.75 mA) based on compact H-/D- cyclotron, CYCIAE-70, has been designed at CIAE in Beijing for the RIB production and application in the nuclear medicine recently. CYCIAE-70 is designed to be a dual particle cyclotron and it is able to deliver proton with energy in the range 35~70 MeV and deuteron beam with energy in a range of about 18~33 MeV. About 700μA for H+ and 40μA for D+ will be extracted in dual opposite directions by charge exchange stripping devices and the extraction beam energy is continuously adjustable. The physics design of CYCIAE-70 stripping system has been done and the optics calculation for the extraction proton and deuteron beam has been finished. The dispersion effects for the extracted beam are analyzed and the beam parameters after extraction are calculated. 6 beam transport lines and experiment target stations are designed for different applications. A wobbling magnet is used in one of the beam transport lines, which will rotate the beam to form a beam spot on the target with a size of Φ40mm and uniformity of better than 95%.

INTRODUCTION

In order to afford the applications in the radioactive ion-beam (RIB) production and the filed of nuclear medicine, a multi-functional compact cyclotron CYCIAE-70 [1] is completely designed at China Institute of Atomic Energy under the accumulated experience on the physical research and technology design of the H- high intensity cyclotron [2,3]. The machine adopts a compact structure with four straight sector poles, capable of accelerating two kinds of beams, i.e. H- and D-. The proton beam in the range 35~70 MeV with an intensity up to 700μA, and the deuteron beam with 18~33 MeV and 40μA will be extracted in dual opposite directions by charge exchange stripping devices. For both particles that are extracted, the energy is continuously adjustable.

The cyclotron will be equipped with two combination magnets, placed at 180° one respect to the other. Any proton beam extracted by the stripper in the energy range 35~70MeV, will be transported at a crossover point inside one of the extraction combination magnets. The crossover point is the starting point of the extraction line. One of the two extraction magnets has to be equipped with a beam transport line to transport the full power beam outside the cyclotron and inside the commissioning room. In order to reduce the time of changing foils, the stripping foil changing devices are put in the independent vacuum chamber. Two stripping probes with carbon foil are inserted radially in the opposite direction from the main magnet pole. By comparing the optic calculating results for the extracted beam, the combination magnet is fixed between the adjacent yokes of main magnet in the direction of valley region. To keep all the extracted beams with various energies can be transported through the same crossing point in the combination magnet, the stripping probe can be moved in the radial direction and rotated in the angular direction.

6 beam lines and experiment target stations in the design will meet different users' demands in a variety of application fields. High extraction efficiency and low beam loss are designed for the striping extraction beam lines. Optics matching of the beam lines with the matrix of fringe field and the dispersion effects are taken into account during the extraction. A wobbling magnet is used in one of the beam transport lines, which will rotate the beam to form a beam spot on the target with a size of Φ40mm and uniformity of better than 95%.

STRIPPING FOIL AND SWITCH MAGNET

The positions of the stripping points and the combination magnet are fixed by calculating the extraction trajectories of extracted proton beams and deuteron beams after stripping foil for different energy with the code CYCTR [4]. In order to reduce the envelope of extracted beam, the combination magnet is fixed at the adjacent yokes of main magnet in the direction of valley region. The main magnetic field used to calculate the extraction trajectories is assumed to have mid-plane symmetry. The extracted proton and deuteron beams energies are chosen by the corresponding static equilibrium orbits.

For 70MeV cyclotron, the radius of magnet pole is 1.4 m and the outer radius of magnetism yoke is 225 cm. The center of combination magnet is located at R＝200 cm and THETA=100o). Table 1 shows the stripping points for the extracted proton beam and deuteron beam for different energies.

Table1: Position of stripping foil at different extraction energies for H- and D-.

H^-			D^-		
Energy (MeV)	R (cm)	Theta (°)	Energy (MeV)	R (cm)	Theta (°)
70	126.81	58.70	35	132.23	58.39
50	109.18	57.15	25	112.72	56.74
35	92.59	55.97	18	96.07	55.68

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In order to extract the H- and D- beams with different energies, the stripping probe is inserted in the radial direction from the sector pole to the cyclotron center along the line of 57.2°. The minimal inserted position of the stripping probes is at R=92 cm. In order to extract beams at different energies, the stripping probe can be moved along the radial direction and rotate along the angle direction with a swaying angle of ±5°. Figure 1 shows the position of combination magnet and the extracted trajectories of proton beams with energy of 35MeV, 50MeV, 70MeV respectively.

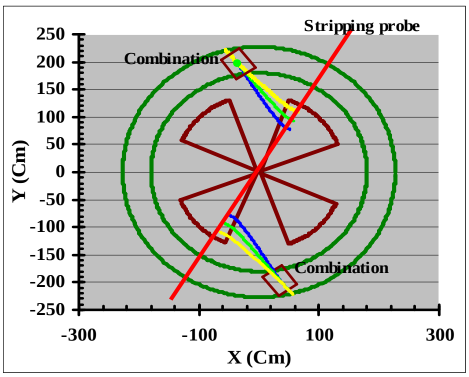

Fig.1 The stripping probe and extracted proton beam orbits with 35MeV, 50MeV, 70MeV.

In order to reduce the time of changing foils, the stripping foil changing devices are put in the independent vacuum chamber. Figure 2 shows the assembly of stripping extractor for H- and D- extraction and the foil changing system. The foil automatic changing machine is outside the magnetism yoke and 12 pieces foil can be changed in one time. For the stripping extraction system, the carbon foil will be used. For the extracted energy of 70MeV, the stripping efficiency is about 99.96% when the carbon foil thickness is 120 μg/cm^2 [4]. So, the foil thickness of 120 ~ 130 μg/cm^2 is enough for this machine.

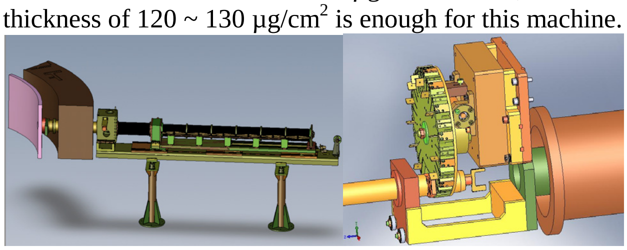

Fig. 2 Stripping Extractor and Foil changing devices.

The structure of the combination magnet is designed, and the main field 0.5T, Gap g=80 mm, Bending radius R=2968.2 mm, Effective length of the magnet Leff=300 mm, Maximum bending angle 5.79°, Uniform field range 80 mm, Mechanical length of magnetic pole 234 mm, $\Delta B/B<5.78\times10^{-4}$.

THE EFFECTS OF DISPERSION

The dispersion effects caused by the main magnet fringe field should be considered during the designs of the extraction system and beam transfer line. Due to the asymmetric magnetic field, the dispersion will be produced and this will lead to the emittance growth in x direction. The dispersion from stripping foil to the center of combination magnet (cross-over point) will be got from the modified code GOBLIN by CIAE [5]. Table 2 is the transfer matrix from stripping foil to the cross-over point with dispersion for different beam energy. Figure 3 shows the dispersion for the extracted proton beam from stripping point to the cross-over point. Not shown the case of D+ beam, which is very similar as the case of H+ beam.

Table 2 The transfer matrix from stripping points to the center of combination magnet.

Ion	H^+			D^+		
E/MeV	70	50	35	35	25	18
R_{11}/1	0.968	1.051	1.158	0.801	0.874	1.009
R_{12}/cm/mrad	0.163	0.178	0.190	0.156	0.171	0.185
R_{16}/cm/%	0.578	0.709	0.837	0.539	0.668	0.798
R_{21}/mrad/cm	-0.604	0.738	1.031	-2.117	-0.739	0.359
R_{22}/1	0.931	1.076	1.032	0.837	0.999	1.057
R_{26}/mrad/%	4.588	4.533	3.874	4.547	4.380	4.107
R_{51}/1	-0.479	-0.424	-0.362	-0.479	-0.432	-0.386
R_{52}/cm/mrad	-0.021	-0.004	0.013	-0.026	-0.008	0.009
R_{56}/cm/%	1.325	1.506	1.701	1.464	1.609	1.759
R_{33}/1	0.399	0.057	-0.415	0.601	0.278	-0.183
R_{34}/cm/mrad	0.148	0.145	0.141	0.154	0.153	0.147
R_{43}/mrad/cm	-4.155	-6.576	-9.313	-2.471	-4.858	-7.788
R_{44}/1	0.965	0.840	0.756	1.029	0.928	0.787

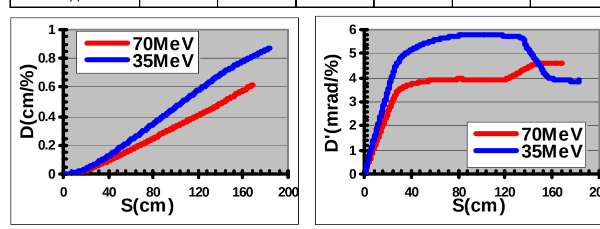

Fig.3 The dispersion for the extracted proton beam from stripping point to the cross-over point.

STRIPPING EXTRACTION SIMULATION

The extracted beam distribution just after stripping foil can be got from the modified multi-particle tracking code COMA by CIAE [6]. Not only the case of 180° dees in TRIUMF, but also accelerating gap with general dee geometry is includeded in COMA. Gaussian input distribution and linear space charge calculation are added for the modified code COMA.

Figure 4 shows 1.5 MeV H- input phase space distribution and the extracted 70 MeV H+ beam distributions on the stripping foil with the initial normalized emittance of 4.0π-mm-mrad, which is the transverse acceptance of cyclotron central region. The injected is H- bunch with phase extension of Δφ=40°, but zero energy spread. The input distribution is random in transverse direction and uniform in longitudinal direction. The beam parameters for the extracted H+ with different energies can be got from the distributions on the foil, this is the beginning point of the beam transport line for all beam lines design. From the simulation results, the initial normalized emittance of $\varepsilon_x=\varepsilon_z=4\pi$-mm-mrad used in the calculation is reasonable [7]. For the CYCIAE-70, the phase acceptance is 40° to get high current and the energy spread for the extracted beam is about ±0.6%.

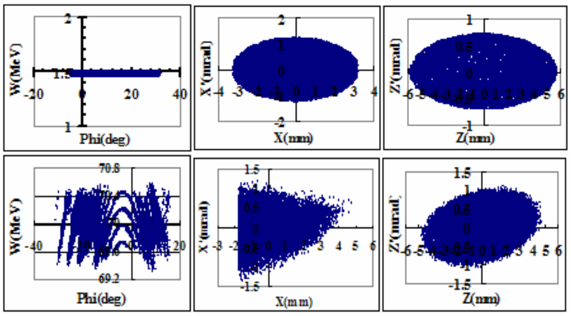

Fig.4 The phase space distributions of initial beam (upper), extracted 70MeV H+ beam on the stripping foil.

BEAM LINE DESIGN

6 beam lines and experiment target stations in the design will meet different users' demands. This system can transport 35-70 MeV, 700μA H+ beam or 18-35 MeV, 40μA D+ beam to the target. High extraction efficiency and low beam loss are designed for the striping extraction beam lines. The beam optics and the layout of the extraction beam line, designs of the main component like bending magnets, steerers, quadrupoles lens, diagnostic devices, vacuum pumps, vacuum-meter etc. have been finished. Figure 5 shows the layout of beamlines.

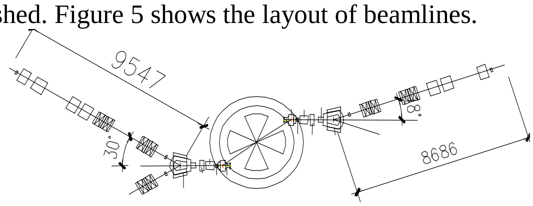

Fig. 5 The layout of beamlines.

The beam parameters as the beginning point of the whole beam line design can be got from the distributions on the foil. Figure 6 shows the beam envelope of one of beam lines. The beam current density uniformity must be better 95% on the target with a size of Φ40mm, so a wobbling magnet is selected. The position of wobbling magnet is about 4.8m before the target. The needed maximum filed is about 200 Gauss to get the beam offset 10.5 mm on the target. The spot on the target can be controlled to be 12mm×18mm and can reach Φ40 mm by using the wobbling magnet, as shown in Figure 7.

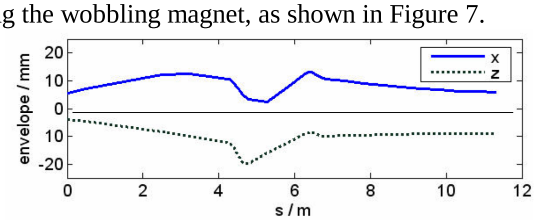

Fig. 6 Total beam envelopes along one beam line.

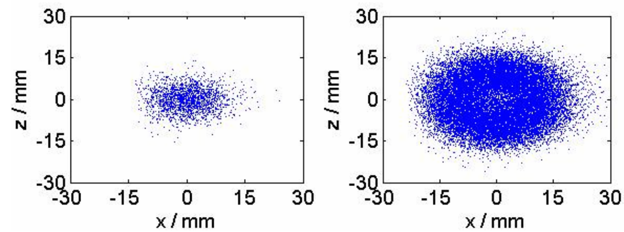

Fig.7 Particles distribution on target without (left) and with (right) wobbling magnet.

SUMMARY

CYCIAE-70, a compact cyclotron with high intensity, will produce proton beam with energy 35-70 MeV and deuteron beam with energy 18-35 MeV. The design intensity is up to 700μA for proton beam and 40μA for deuteron beam with the stripping foil. The positions of the stripping points and the combination magnet are fixed by calculating the extraction trajectories of proton beams and deuteron beams after stripping foil for different energy. The physics designs of CYCIAE-70 stripping system and the combination magnet have been done and the optics calculations for the extracted proton and deuteron beam have been finished. 6 beam lines and experiment target stations in the design will meet different users' demands. High extraction efficiency and low beam loss are designed for the striping extraction beam lines. Optics matching of the beam lines with the matrix of fringe field and the dispersion effects are taken into account during the extraction. A wobbling magnet is used in one of the beam transport lines, which will rotate the beam to form a beam spot on the target with a size of Φ40mm and uniformity of better than 95%.

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