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THE DESIGN AND SIMULATION ON THE EXTRACTION SYSTEM FOR CYCIAE-50

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Abstract

A 50 MeV H^- compact cyclotron as a proton irradiation facility is under construction at China Institute of Atomic Energy (CYCIAE-50). The proton beam with the energy of 30 MeV to 50 MeV and the current of 10 μA will be extracted by a single stripping extraction system. In order to reduce the beam loss, the combination magnet is fixed inside the magnetism yoke. The positions of stripping points for the different extraction energy are calculated and the extracted beam trajectories after stripping foil are simulated in detail in this paper. The extracted beam distribution after stripping foil and the extracted beam characters will be studied in this paper. The beam parameters after extraction will be given by the extracting orbit simulation. The design on the whole stripping extraction system has been finished and will be presented in this paper.

INTRODUCTION

China Institute of Atomic Energy (CIAE) has been devoted to the development of the technologies on proton cyclotrons with high intensity and medium & high energy superconductive proton cyclotrons since 1958, when the first cyclotron had been built at CIAE [1]. CIAE has successively built a series of high intensity beam proton cyclotron with different energy ranges of 10 - 100 MeV [2-5]. For 100 MeV H^- cyclotron at CIAE (CYCIAE-100), more than 1 mA beam has been used on the internal target and maximum proton beam current of 520 μA was used on the power target last year [6, 7]. In order to study the radiation damage to spacecraft materials and devices induced single-particle effects in the space radiation environment, a 50 MeV H^- compact cyclotron as a proton irradiation facility is under construction at CIAE (CYCIAE-50).

CYCIAE-50 consists of a 50 MeV proton cyclotron, two beam lines and two radiation effect simulation experimental target station. The 50 MeV proton cyclotron is a compact cyclotron with the proton beam energy from 30 - 50 MeV, and the beam intensity is from 10 nA to 10 μA. The cyclotron is about 3.2 m in diameter, 3.5 m in total height and 80 t in total weight. The proton beam will be extracted by a single movable stripping extraction system. In order to reduce the beam loss, the combination magnet is fixed inside the magnetism yoke. The extracted proton energy can be extracted continuously by changing the stripping position in the radial direction under the fixed magnetic field and RF frequency. A single stripping probe with a piece of carbon foil will be inserted radially from the main magnet pole. The proton beams with the energy range of 30 - 50 MeV will be extracted by charge exchange with stripping foil and then be transported into the crossing point in a combination magnet center separately under the fixed main magnetic field. The combination magnet is fixed between the adjacent yokes of main magnet in the direction of valley region. The difference of stripping extraction system between CYCIAE-50 and CYCIAE-100 is only single stripping probe is chosen and no foil changing system is used for CYCIAE-50 due to the much lower extracted beam current of 10 μA.

The extracted beam optic trajectories are studied in detail in this paper. To keep all the proton beams with various energies 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. The positions of stripping points for the different extraction energy are calculated. The extracted beam trajectories after stripping foil and the extracted beam distribution on the stripping foil are simulated in detail in this paper. The design on the combination magnet will be given in this paper too.

THE POSITIONS OF COMBINATION MAGNET AND STRIPPING FOIL

The positions of the stripping points and the combination magnet are chosen by calculating the extraction trajectories of extracted proton beams after stripping foil for different energy with the code CYCTR, which is developed by CIAE [8]. The main magnetic field used to calculate the extraction trajectories is assumed to have midplane symmetry. The extracted beam energy is chosen by the corresponding static equilibrium orbit, which is calculated with the code CYClOP [9].

For CYCIAE-50, the radius of magnet pole is 1.0 m and the combination magnet will be set at the position of ($R = 1.75$ m, $\theta = 100°$). Figure 1 shows the position of combination magnet and the extracted beam trajectories from the stripping foil to the combination magnet center for different energies. The red lines are the equilibrium orbits. Table 1 shows the positions of stripping foil with the extraction energy between 20 MeV and 50 MeV. The stripping probe is inserted in the radial direction from the main magnet pole and proton beam will be extracted from the direction of valley. The stripping foil is at ($R = 0.9374$ m, $\theta = 58°$) for 50 MeV and ($R = 0.7399$ m, $\theta = 56°$) for 30 MeV. So, the stripping probe needs to be

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inserted radially from the magnetism pole and the minimal radius of inserting the foil is 0.6 m.

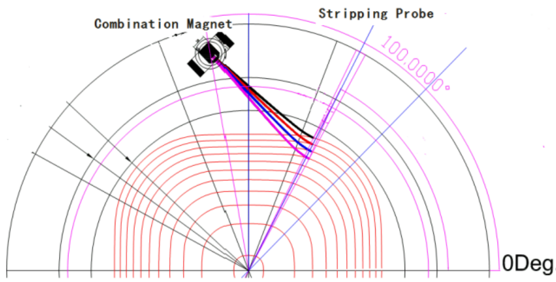

Figure 1: Stripping probe and position of combination magnet. (The red lines are equilibrium orbits).

Table 1: Position of Stripping Foil with Different Extraction Energy, Combination Magnet is Located Closed to the Magnet Yoke with (1.75 m, 100°)

E (MeV)	**R** (M)	**θ** (Degree)
50	0.9374	57.99
40	0.8464	56.97
30	0.7399	56.05
20	0.6092	55.28

THE EXTRACTING TRAJECTORIES WITH COMBINATION MAGNET

Figure 2 shows the extraction trajectory including the fields of combination magnet for the extracted energy of 30 - 50 MeV. The field of combination magnet is different for different extracted energy and the bending angle is ±5°. The field is zero for the extracted energy of 40 MeV. With the different fields, the extracted proton beam with different energy after stripping foil will go through the crossing point of the combination magnet center which is located at the position of (1.75 m, 100°) and will be extracted along the same direction afterwards. The extracted proton beam trajectories for the energy of 30 MeV to 50 MeV can be calculated with the code of CYCTR.

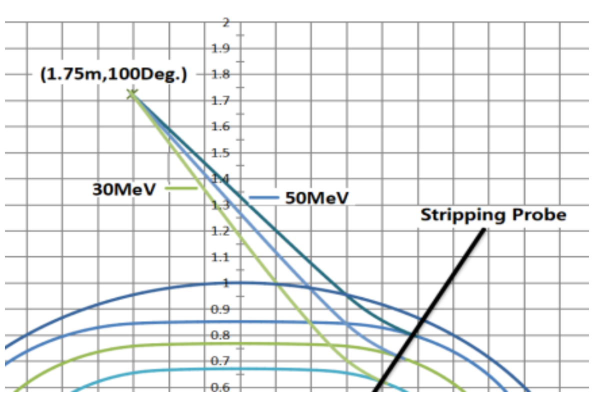

Figure 2: The extracted trajectories with the combination magnet fields for different energies.

THE EXTRACTED BEAM DISTRIBUTION ON THE STRIPPING FOIL

The extracted beam distribution on the stripping foil can be got from the multi-particle tracking code COMA [10]. The H^- beam is injected from the symmetry center of valley with azimuth $\theta = 0°$, and the beam will be tracked along the inserting direction of stripping probe. The initial beam energy is 1.85 MeV at the radius of R = 17.4 cm. The choice of the initial normalized emittance of 0.01 cm^2 or $\varepsilon_x = \varepsilon_z = 4\,\pi$·mm·mrad for CYCIAE-50, which is the same as the case of CYCIAE-100 used in the COMA. The input phase space distributions are uniform in transverse direction and Gaussian in longitudinal direction with the phase extension of $\Delta\phi = \pm 20°$, 20000 macro particles are used in the simulation. Figure 3 shows the input initial phase space distribution and Fig. 4 shows the extracted beam phase space distributions on the stripping foil with the energy of 50 MeV.

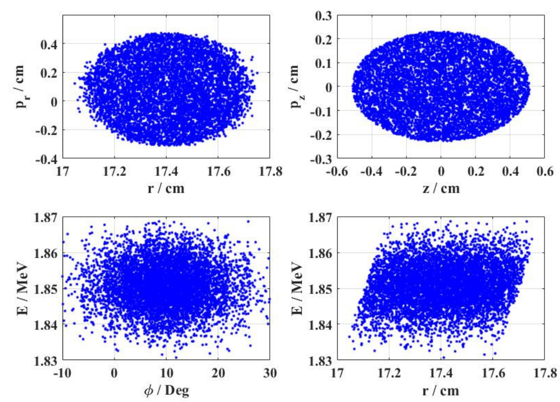

Figure 3: Initial phase space distribution with the normalized emittance of 4.0 π·mm·mrad and phase width of ±20°.

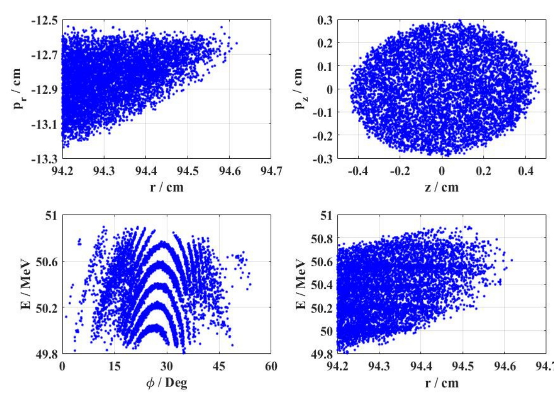

Figure 4: The extracted beam phase space distribution for 50 MeV on the stripping foil.

The extracted beam phase space distribution for 30 MeV on the stripping foil is similar as the case of 50 MeV. From the simulation, the normalized emittance for the extracted proton beam on the foil is almost the same as the initial case. The beam profile on the foil is

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about 5mm×9mm and the energy spread is about ±1.0% for 50 MeV.

THE DESIGNS OF THE EXTRACTED SYSTEM

The designs for stripping extracted system of CYCIAE-50 have been finished. A single movable stripping probe with a piece of carbon foil can move from 30 MeV to 50 MeV. Figure 5 shows the structure of the movable stripping probe. The stripping probe can be moved along the radial direction and rotated along the angle direction. The precision of radial movement is limited about 0.01 cm. The minimum radius which the stripping probe can be inserted is 0.7 m and the rotation range of the probe is ±3°. Only one piece of carbon foil is used for the system and the foil thickness of 120 - 150 μg/cm^2 is enough for CYCIAE-50. The stripping efficiency is about 99.99%.

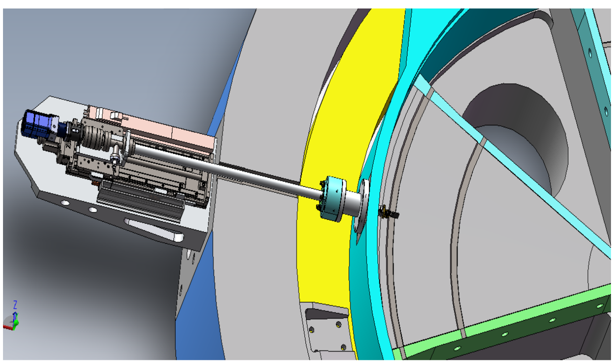

Figure 5: The structure of the movable stripping probe.

The combination magnet in the 50 MeV stripping exchange extraction system is placed at the position of R= 1.75 m, θ =100˚. The combination magnet design is very similar as the case of CYCIAE-100 [11]. The structure of the combination magnet is shown in Fig. 6. The maximum of the field is 0.35T. The maximum bending angle of beam is 5^{o}. The field is -1.5 kG for 30 MeV and 3.5 kG for 50 MeV. The Bending radius is 2968 mm and the gap is 82 mm.

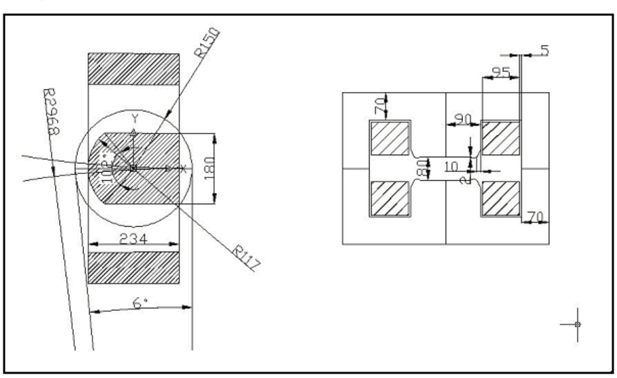

Figure 6: The structure of the combination magnet.

CONCLUSION

All the calculation and simulation on the stripping extraction system has been finished for CYCIAE-50. It is very similar as the case of CYCIAE-100. A single movable stripping probe is adopted in the extraction system. Because the extracted proton beam current is limited less than 10 μA, only a piece of carbon foil will be used to extract the proton beam from 30 - 50 MeV and no foil changing system is used in this machine. All the detail design of the stripping extraction system for CYCIAE-50 has been finished and is being manufactured now. Beam commissioning is expected to be done at the end of the next year.

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REFERENCES

[1] Fan Mingwu, Zhang Xingzhi, Li Zhenguo *et al.*, “Construction of high current proton cyclotron CYCIAE-30”, Chinese Science Bulletin, 1995， CN 11-1784/N, vol. 40, no. 1, p. 825.

[2] T. J. Zhang, L. I. Zhenguo, A. N. Shizhong *et al.*, “The cyclotron development activities at CIAE”, *Nucl. Instrum. Methods Phys. Res., Sect. B*, vol. 269, no. 24, pp. 2863-2870, Dec. 2011. doi:10.1016/j.nimb.2011.04.047

[3] T. J. Zhang, Li Zhen-Guo, Chu Cheng-Jieo, *et al.*, “Test stand design and construction for high intensity, cyclotron development”, *Chinese Physics C*, vol. 32, no. S1, p. 237, 2008.

[4] T. J. Zhang, Lu Yinlong, Yin Zhiguo, *et al.*, “Overall design of CYCIAE-14, a 14 MeV PET cyclotron”, *Nucl. Instrum. Methods Phys. Res., Sect. B*, vol. 269, no. 24, pp. 2950-2954, Dec. 2011. doi:10.1016/j.nimb.2011.04.049

[5] T. J. Zhang, J. Yang, “The beam commissioning of BRIF and future cyclotron development at CIAE”, *Nucl. Instrum. Methods Phys. Res., Sect. B*, vol. 376, pp. 434-439, 2016. doi:10.1016/j.nimb.2016.01.022

[6] T. Zhang, S. An, Y. Lv, *et al.*, “mA beam acceleration efforts on 100 MeV H$^-$ cyclotron at CIAE”, *Nucl. Instrum. Methods Phys. Res., Sect. B*, vol. 406A. A, pp. 250-255, Sept. 2017. doi:10.1016/j.nimb.2016.11.024

[7] Sumin Wei, Tianjue Zhang, Feng Wang, Shizhong An *et al.*, “Study and construction of a 100 MeV high power proton beam line”, Atomic Energy Science and Technology, ISSN 1000-6931, CN 11-2044/TL, 2019.

[8] An Shizhong, Guan Fengping, Xie Huaidong *et al.*, “Stripping extraction calculation and simulation for CYCIAE-100”, *Chinese Physics C*, vol. 33, no. S2, pp. 42-47, Jun. 2009. doi:10.1088/1674-1137/33/S2/011

[9] M. M. Gordon, “Computation of closed orbits and basic focusing properties for sector-focused cyclotrons and the design of cyclops”, *Part. Accel*, vol. 16, pp. 39-62, 1984.

ISBN: 978-3-95450-205-9 doi:10.18429/JACoW-Cyclotrons2019-MOP006

[10] C. J. Kost, G. H. Mackezie, "COMA – A linear motion code for cyclotron", *IEEE Transact. Nucl. Sci.*, vol. 22, no. 3, Jun. 1975. doi:10.1109/TNS.1975.4328029

[11] S. M. Wei, M. Li, C. Wang, M. Yin, T. J. Zhang, and X. Zheng, "Design and construction of combination magnet for CYCIAE-100", in *Proc. Cyclotrons'13*, Vancouver, Canada, Sep. 2013, paper TUPSH002, pp. 221-223.