Study of energy deposition and stripper temperature for CYCIAE-100*

WEI Su-Min(魏素敏)[1;1)] ZHANG Tian-Jue(张天爵)[1] AN Shi-Zhong(安世忠)[1] BI Yuan-Jie(毕远杰)[1,2]

1 (China Institute of Atomic Energy, Beijing 102413, China)
2 (Department of Engineering Physics, Tsinghua University, Beijing 100084, China)

Abstract Nowadays high intensity proton accelerators are extensively applied, and this paper gives particular emphasis on CYCIAE-100, a 100 MeV high intensity compact cyclotron being constructed at CIAE. For accelerators of this type, the study is focused on how to improve the beam intensity. As for CYCIAE-100, the charge-exchange extraction is used to get protons. So it is crucial to enhance the lifetime of the stripping foil, which is largely determined by the energy deposition on it. For this cyclotron, due to the influence of the magnetic field, the electrons will spin near the foil and lose energy each time when they cross the foil. The energy deposition refers to all the energy deposition of protons and electrons. This paper stresses the stripper study of CYCIAE-100, in which the particle distribution on the foil is simulated and the energy deposition of the protons and electrons stripped from the H^- ions are calculated. The temperature distributions are then calculated as a main reference for the foil design.

Key words cyclotron, stripping foil, particle distribution, energy deposition, temperature distribution

PACS 41.85.Ar

1 Introduction

Along with the development of high intensity proton accelerators which are extensively applied nowadays, it is very important to improve the beam intensity for them. As is well known, most proton accelerators in the world obtain protons by charge-exchange injection or extraction, and according to the general practice, the lifetime of the foil is reduced as the beam intensity increases. To get a steady beam, the short lifetime of the foil fails to qualify the design. That makes it crucial to enhance the lifetime of the stripping foil.

The lifetime of the foils is determined by many factors, such as temperature distribution, material of the foil, mechanical support, etc., among which the temperature distribution is of key importance. To simulate the temperature of the foil, the energy distribution on the foil should be obtained. This paper studies the energy deposition and the temperature distribution on the foil of a compact high intensity cyclotron CYCIAE-100[1].

CYCIAE-100 is a main part of the project BRIF (Beijing Radioactive Ion-beam Facility), and is designed to provide a 75 MeV ~ 100 MeV, 200 μA ~ 500 μA proton beam after the completion of the project. To get the energy distribution, the particle distribution on the foil is simulated by the code COMA. Based on this result, a matlab code has been used to calculate the energy deposition of the protons and electrons stripped from the H^- ions. For CYCIAE-100, there is no electron-collecting system after the stripping foil, so the electrons will spin near the foil under the influence of the magnetic field, and will lose energy each time when they cross the foil.

The temperature distribution is then simulated on the basis of the energy deposition, and the result serves to be a main reference for the foil design. This paper will illustrate the energy deposition and the temperature distribution for CYCIAE-100.

Received 6 January 2009
* Supported by BRIF Project
1) E-mail: weisumin@tsinghua.org.cn

2 The behavior of the beam through the foil and beam distribution on the foil

CYCIAE-100 adopts a charge-exchange method to get protons, and it is useful to study the beam behavior on the stripping foil. It is well known that for H^- beam above 100 keV, when it traverses the stripping foil, the cross sections for electron pickup are very small and can be neglected[2], so for CYCIAE-100, the H^- and H^0 can be neglected behind the foil. When the foil thickness is 150 μg/cm^2, the stripping efficiency of the beam is almost 99.9% at 100 MeV[3]. That is to say almost all H^- ions are changed into protons and electrons and contribute to the energy deposition.

In the cyclotron, under the influence of the magnetic field, the electrons will spin near the foil and lose energy each time when they cross the foil as is shown in Fig. 1.

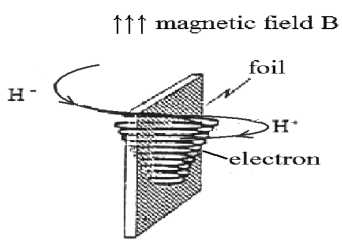

Fig. 1. The beam behaviour on the stripping foil.

So the energy deposition contains the H- and the whole energy deposition of the electrons, and it can be noticed that each H^- ion changes into one proton and two electrons after the foil:

$$E_{\text{deposition}} = E_{H^-} + E_{\text{electron}} \ . \tag{1}$$

The particle distribution on the foil should be available before proceeding to simulate the energy deposition. Fig. 2 shows this distribution of CYCIAE-100 at a beam energy of 100 MeV. It is calculated by a beam dynamic code COMA[3]. A beam dimension of 12 mm in vertical and 7 mm in transverse can be achieved.

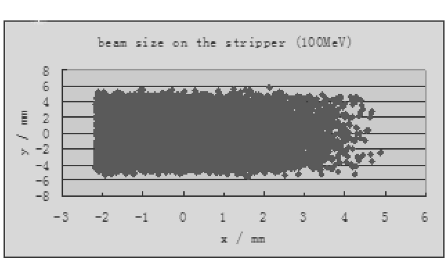

Fig. 2. Particles distribution on the stripping foil.

3 Energy distribution on the foil

For CYCIAE-100, a carbon foil is selected as the stripper as shown in Fig. 3. It is 0.15 mg/cm^2, 30 mm in height and 20 mm in width. The aluminum frame is 10 mm high and located right above the foil. From the beam size calculation mentioned above, the proton spot of 7 mm wide and 12 mm high is selected as shown below for a primary calculation.

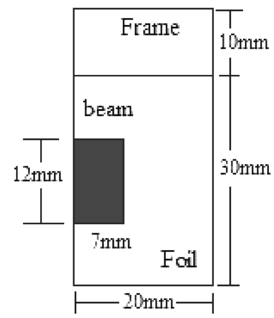

Fig. 3. A model of carbon foil for calculation.

For each 100 MeV H^-, the energy deposition in the carbon foil is $\mathrm{d}E/\mathrm{d}z$ = 6.538 keV/(mg/cm^2), where z is the thickness of the foil. The H^- energy deposition can be expressed as:

$$E_{H^-} = \frac{\mathrm{d}E}{\mathrm{d}z} Z \ . \tag{2}$$

For the electrons, they will be spiral near the foil and lose energy each time when they cross the foil, and the rms angle of the projected angular distribution of electrons can be parameterized as[4]:

$$\theta_{\text{rms}} = \frac{45\sqrt{Z}}{2E} \ , \tag{3}$$

where Z is the foil thickness in mg/cm^2, E is the electron energy in MeV. So after crossing the foil the actual scattering angle is calculated with a randomly selected number from a normal distribution whose mean value is θ_{rms}.

For the carbon foil, we can get a dE-E curve (deposited energy and entrance energy) of the electrons at an entrance energy of less than 300 keV. It is calculated from a stopping power table ESTAR and then parameterized as:

$$\Delta E = Z \times 110.99 E^{-0.7473} \ , \tag{4}$$

where ΔE is the energy deposition of the electron in keV, E is the entrance energy in keV (less than 300 keV). So we can calculate the electron energy deposition each time when they cross the foil at different entrance energy.

The energy distribution calculation of the H- and electrons has been performed with a matlab code. The formula and parameters used in the code are described above. Both uniform and linear distributions (that means the particle distribution in x-axis is linearly with x) of the beam are considered, and meanwhile, the actions of electrons in the magnetic field are included in these results. For a 200 μA, 100 MeV beam, the H^- energy deposition on the foil is 0.2 W, the total energy deposition of the electrons on the foil and the frame is almost 15 W; others are lost in the cyclotron, which is about 3 W. In our case, one electron is supposed to cross the foil for 21 times on average.

Figure 4 shows the energy deposition on the foil and the frame. The upper part is of the uniform beam and the lower part is of the linear beam. In each part, the left one is the H- energy deposition, each H^- ion will cross the foil once; the middle one is the electron energy deposition on the foil, each electron will cross the foil several times and lose its energy. Some of the electrons will hit the frame because of the magnetic field, and the right one shows the electron energy deposition on the frame.

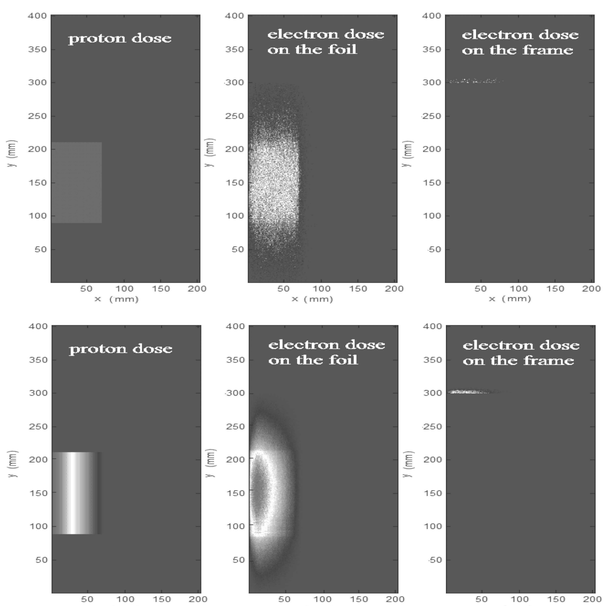

Fig. 4. Energy deposition of uniformly beam and linear beam.

4 Temperature distribution on the foil

Based on the energy deposition on the stripping foil, the temperature simulation has been conducted with the 3D finite element software ANSYS CFX. Fig. 5 shows the temperature distribution of the stripper when the uniform beam hits the foil.

Further calculation will be done for the strippers with different thickness and different beam shape.

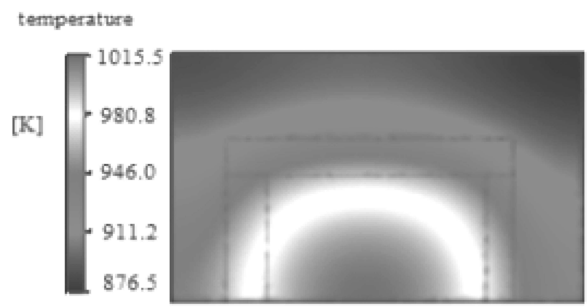

Fig. 5. Temperature distribution on the foil.

5 Summary

To improve the beam intensity, the lifetime of the stripping foils of CYCIAE-100 is studied, including the energy deposition and the temperature distribution on the foils. The proton distribution on the foil is simulated by code COMA. The energy deposition of the protons and the electrons that spin near the foil are calculated by a matlab code. The temperature distribution is then calculated and shown. Further calculation is to be performed for the lifetime study.

The author thanks Dr. Marco Schippers from PSI for his contribution to this paper, and also thanks the host institution TRIUMF.

References

1 ZHANG Tian-Jue et al. Proceeding of the APAC. 2004, 267—269

2 Robert C. Webber, Carlos Hojvat. Measurement of the Loss Cross Sections for Negative Hydrogen Ions on Carbon at 200 MeV. IEEE Transactions on Nuclear Science, 1979, **NS-26**(3)

3 AN Shi-Zhong et al. Study of Stripping Efficiency for CYCIAE-100, CIAE Annals Report (in Chinese), 2007

4 Marco Schippers. Electron Power Density on the Stripper, Private Communication