DESIGN AND SIMULATION OF A NEW FARADAY CUP FOR ES-200 ELECTROSTATIC ACCELERATOR

E. Ebrahimibasabi, S.A.H. Feghhi, M. Khorsandi, Department of Radiation Application,
Shahid Beheshti University, Tehran, Iran

Abstract

Faraday Cups have been used as diagnostic tools to measure the charged particle beam current directly. Up to now, different designs have been introduced for this purpose. In this work, a new design of Faraday Cup has been performed for ES-200 accelerator, a proton electrostatic accelerator which is installed at SBU. FC's dimensions and desirable material have been considered Based on the ES-200 beam characteristics (maximum energy of 200 keV and maximum current of 500 μA). Thickness and dimensions of FC has been calculated by SRIM and MCNPX codes according to the range of proton and induced electrons. The Appropriate FC geometry specifications have been simulated by using CST Studio package. In addition, the heat power generated by proton collision with FC material has been calculated analytically and then required cooling system has been designed by ANSYS. The results showed that the new designed Faraday Cup has a good performance to measure the proton beam current in ES-200 ion accelerator.

INTRODUCTION

An electrostatic accelerator is a type of accelerator that uses static electric field to accelerate charged particles. ES-200 is a 200 keV electrostatic proton accelerator at Shahid Beheshti University (SBU), which has four main components as shown in Fig (1). In this accelerator; RF ion source is positioned inside the high voltage terminal and injects protons into the accelerating tube. A variable high voltage is used to create a 200 kV potential difference between the ion source and the high voltage terminal. Within the accelerating tube is a strong uniform electric field which accelerates protons toward the target. The vacuum system lowers the pressure of the accelerating tube down to at least 10^{-5} Torr to ensure that the accelerated protons have no interaction with air molecules and energy loss [1]. This machine will require ultra-sensitive instrumentation for its proper operation. So a new design of Faraday Cup (FC) will be considered to do more precise measurement of accelerator beam current.

DESIGN CONCEPTS

FCs are used as a destructive instrument, which can provide accurate information on the beam current in a very straightforward manner [2]. Designing proper cooling system, determining the optimal dimensions of a FC and backscatter loss reduction techniques (including: Geometry-based techniques, Electromagnetic techniques, and using of a low-Z material) are a number of issues that need to be considered for designing a FC [3].

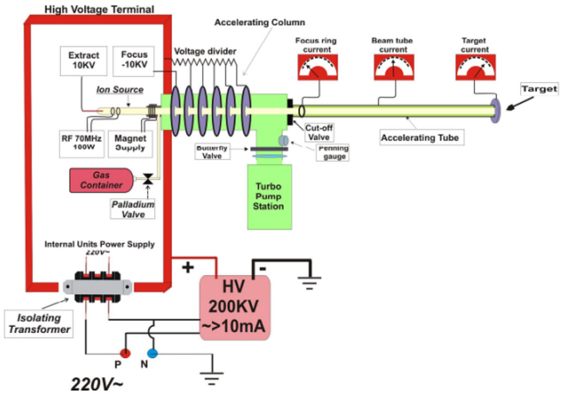

Figure 1: Electrical Schematic of 200keV Electrostatic System [1].

As is shown in Fig (2) heavy charged particles such as proton interact with matter primarily through coulomb forces between their positive and negative charge of the orbital electrons within the absorber atoms [4]. Although nuclear interaction of the charged particle with material (as in Rutherford scattering) is also possible at high energies, but because of the low energy of proton beam in ES-200, forward and backward distribution of electrons due to nuclear interactions could not be possible. The energy spectrum of the secondary electrons, has a peak at a few eV with a spread at half height of the same order of magnitude, thus about 80-95% of emitted particles are below 100 eV [5]. This behaviour may indicate that the emission of low-energy electron is indeed due to the cascade process. High-energy part of the spectrum reflects the direct energy transfer process from the impinging ion to an electron within the matter.

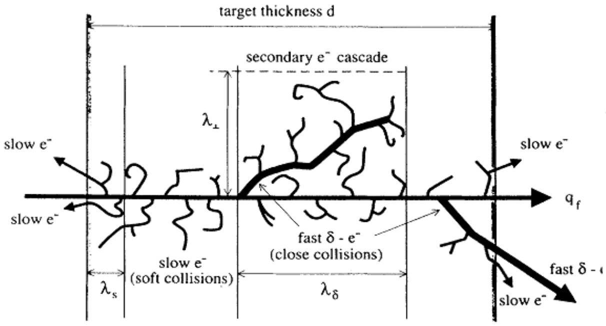

Figure 2: Ionization of the mater by ions and process of electron emission [6].

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The first step in the FC design process involves determination of material, so that the thickness of the beam stopper should be much larger than the penetration depth of 200 keV protons. In this paper, Copper was chosen because of its good electrical conductivity and its excellent heat conductivity [7]. The maximum energy of ejected electrons is given by

$$E_{\max} = 4\frac{m_e m_p}{(m_e + m_p)^2} E_{\max} Cos^2\theta \qquad (1)$$

Where E_{Proton} is the incident proton energy and Θ is the angle between the direction of the incident beam and the trajectory of secondary electrons. m_p and m_e are the proton and electron mass respectively[8]. So for 200 keV protons, the maximum energy transfer to the orbital electrons of copper atoms, as a FC material, is about 459 eV.

It should be mentioned that the target thickness not only depends on the range of protons but also on forward and backward-electron yield [6]. Range of 200 keV protons in copper has been calculated to be 0.99 µm using SRIM code. The same result has been confirmed using MCNPX simulations [9]. According to MCNPX results range of the electron with maximum energy of 459 eV (in forward direction) is 0.5 mm. It seems that a 1mm thickness of neck wall in FC will be enough for our purpose. But to ensure the preservation of the vacuum, the thickness of 3mm has been chosen.

MECHANICAL DESIGN OF FC

Although the angular distribution of high energy electrons has a strongly forwarded peak [6], but by optimization in structure and using a high voltage in cup entrance, the backscattered electrons eject towards the neck wall or the beam stop region.

Using a suitable cone shaped aperture and a proper suppressing voltage; we can reduce the backscatter electrons. Since secondary electrons emission follows a cosine distribution about the normal to the surface, a cone shaped aperture increases the geometrical path length of the impinging particles within the escape region and the total electron yield decrease by a factor of $\cos^{-1}\Theta$ (Θ is The angle of incidence of the beam respect to the surface normal) [2]. In order to redirect the secondary electrons back into the FC, The FC angel of 45^0 leads to radius of 22 mm, and length of 53 mm for a cone shaped aperture. Schematic of the FC, simulated by CST Studio package, has been shown in Fig.3 [10]. Suppressor material close to the entrance of the cup was considered of stainless steel to prevent the secondary electrons leaving the FC. The position and dimension of this segment is very important to reduce the necessary suppressing voltage. For electric isolation of the cup components, ceramic was used. According to selected angle, suppressing voltage -230 V is sufficient to capture all of charges in the FC.

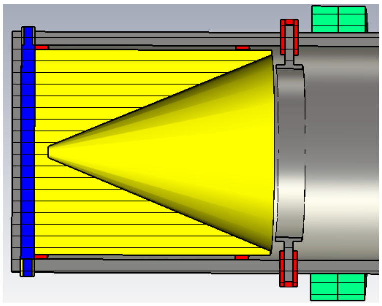

Figure 3: final design of the FC simulated with CST.

Fig (4) and Fig (5) shows Simulations of the field distribution and the secondary electron emission modelled with the CST Studio package respectively.

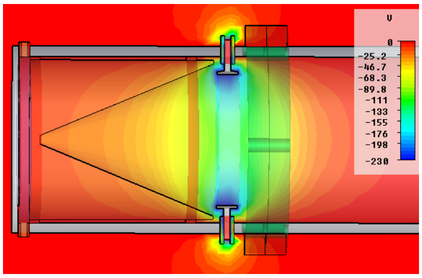

Figure 4: Simulation of the field distribution.

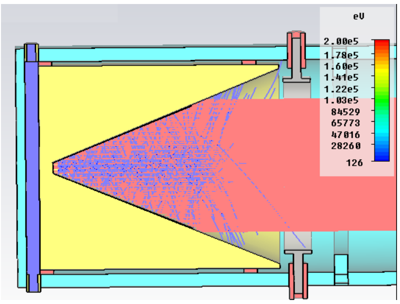

Figure 5: Simulation of secondary electrons emission.

HEAT TRANSFER

According to the simulations using ANSYS, produced thermal power in the desired FC, by considering the proton energy of 200 keV and continues beam current of 500 µA, will not exceed 100 W. A cooling system has been designed so that a pipe with diameter of 0.3 cm, that covers whole backward side of FC, extracts the produced heat. The used cooling water system has been depicted in Fig. 6. Simulation of cooling water system was done by ANSYS [11]. In this system, temperatures of inlet and outlet water of the coolant tube are about 295 K and 300 K respectively. The simulation results show that, if the water flows with a volumetric flux of 1×10^{-4} m^3s^{-1}, the maximum temperature of FC would be 300 K.

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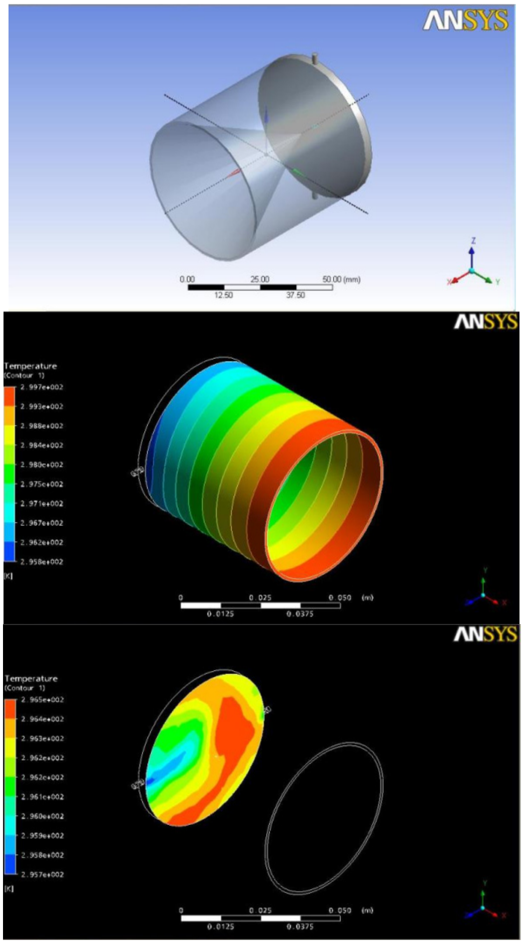

Figure 6: Distribution of heat on cooling system with ANSYS.

RESULTS & CONCLUSION

By choosing copper as proper material for our FC, range of 200 keV protons was calculated by SRIM and MXNPX. Choosing a cone shaped aperture with the angel of 45^0 leads to total electron yield decrease by a factor of 1.4. So that suppressing voltage -230 V can capture all of charges in the FC. In following water cooling system for our FC designed and simulated by ANSYS. Results showed that with a flow of 1×10^{-4} m^3s^{-1}, the maximum temperature of FC could be 300 K.

Based on the results from this work we plane to construct the FC and compare its practical performance with the previous one in our accelerator.

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