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THE OPTIMIZATION DESIGN AND OUTPUT CHARACTERISTIC ANALYSIS OF IONIZATION CHAMBER DOSE MONITOR IN HUST-PTF*

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Abstract

An air parallel-plate ion chamber, which acts as a dose monitor for the beam delivery system in Huazhong University of Science and Technology Proton Therapy Facility (HUST-PTF), is designed as a redundant twin ionization chamber in order to meet the security requirements. In this paper, the characteristics of the designed ionization chamber are studied by using Boag theory and Monte Carlo simulation. Geant4 and SRIM are applied to simulate the energy loss and gain of 70-230MeV proton beam in parallel-plate ionization chamber. The influences of different sensitive regions and different gases on the performance of proton beam are discussed, moreover the structure of ionization chamber is optimized. According to the theory of Boag, the collection efficiencies of ionization chamber under different bias are calculated. The results show that the secondary particle collection efficiency of ionization chamber can reach above 99% when the air gap of ionization chamber is 5mm and bias voltage is above 100V. By the calculated gain of the ionization chamber, the output current of the detector can reach the order of 10nA when the proton beam intensity is 0.1nA.

INTRODUCTION

Nowadays, proton therapy facility is one of the most effective radiation therapy methods for cancers which use the Bragg peak characteristic of proton to achieve the precise irradiation of the tumor. The proton beam is tested with a dose detector in the nozzle before treating the patient, to ensure the efficacy of the treatment and the patient's safety. An air ionization chamber is used as a dose detector in Huazhong University of Science and Technology Proton Therapy Facility（HUST-PTF）.

The ionization chamber is composed of the cathode plate, the anode plate and the filling gas between the plates. When a proton beam passes through the gas, it disassociates the gas molecules, producing positive ions and electrons. Under the action of electric field, the positive ions move to the cathode while electrons move to the anode, and the secondary particles collected on cathode plate or anode plate reflect the magnitude of the beam current. The charge collected on the electrode plate is amplified and processed by peripheral electronics to obtain the dose of the proton beam.

In this paper, the structure and principle of plate ionization chamber are introduced. The energy loss and gain of different energy proton beams in ionization chamber are calculated by using the Monte Carlo software SRIM [1] and Geant4 [2]. According to Boag theory [3], the collection efficiency of ionization chamber under different bias voltages is calculated.

STRUCTURE AND PRINCIPLE OF PLATE IONIZATION CHAMBER

The structure of plate ionization chamber in HUST-PTF is shown in Fig. 1. The chamber consists of two windows, two cathode plates, an anode plate, and filling gas between plates. The entrance window acts as a seal and supports the ionization chamber. The material for the electrode background and window is Polyimide [4], with a thickness of 10μm. Polyimide has the characteristics of strong radiation resistance, high mechanical strength and high penetrability, and it has little influence on the beam. The gaps between the plates is filled with air, which is the sensitive volume of the ionization chamber. In order to meet the security requirements, the chamber is designed as a redundant twin ionization chamber.

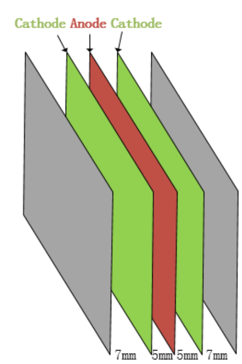

Figure 1: The structure of plate ionization chamber.

When the high-energy proton beam passes through the ionization chamber, the gas molecule is ionized. Due to the composite effect, the secondary particle produced by ionization cannot completely move to the electrode. With the increase of the bias voltage of the anode plate, the positive ions and electrons produced by the proton beam and the ionization of the air are completely collected and saturated. The principle of the ionization chamber is presented in Fig. 2.

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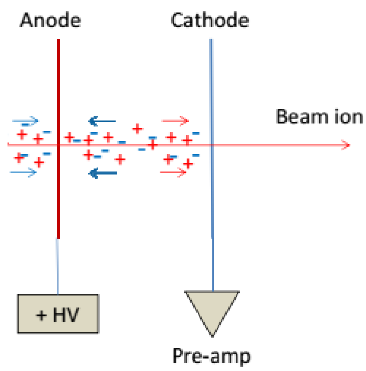

Figure 2: The principle of the ionization chamber.

ENERGY LOSS IN IONIZATION CHAMBER

The energy of the proton beam determines the depth of the Bragg peak, the energy loss of proton beam will affect the beam quality and destroy the therapeutic effect. The energy loss of the 70-230MeV proton beam in the ionization chamber is simulated by using SRIM and Geant4,In the simulations, the state of the gas is 1 atmospheric pressure, 20℃,ρ=1.205g/L, proton number is 20000.The results are listed in Table 1.

Table 1: The Energy Loss of Beam in Ionization Chamber

Proton Energy /MeV	Energy Loss/MeV		Percentage of Initial Energy (%)	
	Geant4	SRIM	Geant4	SRIM
70	0.0224	0.0241	0.032	0.034
100	0.0171	0.0186	0.017	0.019
150	0.0124	0.0139	0.008	0.009
200	0.0104	0.0118	0.005	0.006
230	0.0093	0.0105	0.004	0.005

The energy loss of the 70-230MeV proton beam passing through the ionization chamber is less than 0.032% of the initial energy, meets the treatment requirements. The larger the proton beam energy, the smaller the influence on the beam performance.

GAIN OF PROTON IN IONIZATION CHAMBER

The gain of proton in ionization chamber is the proportional relation between secondary particles and the initial particles. The average ionization energy of protons in air is W=34eV [5]. The energy loss of ionization of a single proton in the air is obtained by simulation, and the number of secondary particles produced by ionization is calculated according to formula (1).The number of secondary particles is the gain.

$$N = \frac{\Delta E}{W} \tag{1}$$

The energy loss of charged particles passing through the target material is divided into two parts: 1. energy loss of inelastic collisions with the nuclear electron of the target atoms (energy loss of ionization); 2.energy loss of elastic collisions with the target nuclei. For high-energy protons, the energy loss is mainly the first part, and the second part is negligible [6]. The energy loss of the 70-230MeV proton in the ionization chamber can be approximately equal to the energy loss of ionization.

Using software SRIM and Geant4 simulation to calculate the gain of 70-230mev proton beam in 5mm air. The results are shown in Fig. 3.

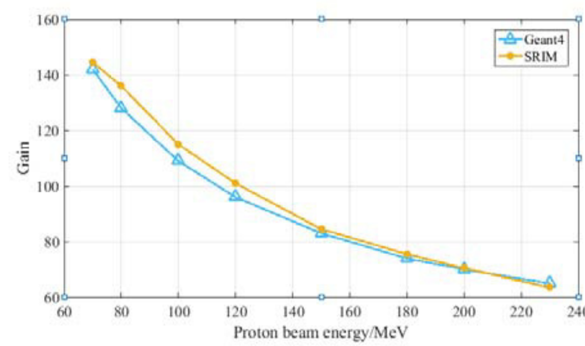

Figure 3: The gain of beam in ionization chamber.

The lower the energy of the proton beam, the greater the gain in the ionization chamber, and the gain of the 70-230MeV proton beam in the ionization chamber is 63-145.The gain in different air states can be obtained by the calibration formula.

$$G_1 = G_0 \times \frac{P_0}{P_1} \times \frac{T_1}{T_0} \tag{2}$$

COLLECTION EFFCIENCY OF IONIZATION CHAMBER

Because of the composite effect, the secondary particle produced by ionization cannot completely move to the electrode. According to Boag theory [3], the collection efficiency of ionization chamber under different bias voltage is calculated.

$$f = \frac{1}{1+\xi^2} \tag{3}$$

$$\xi = m \bullet d^2 \bullet \rho^{1/2} / V \tag{4}$$

Which d is plate spacing, V is bias voltage, ρ is density of air, m is the correction factor of air temperature and air

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pressure (for dry air m = 36.7 + 2.2). The results are presented in Fig. 4.

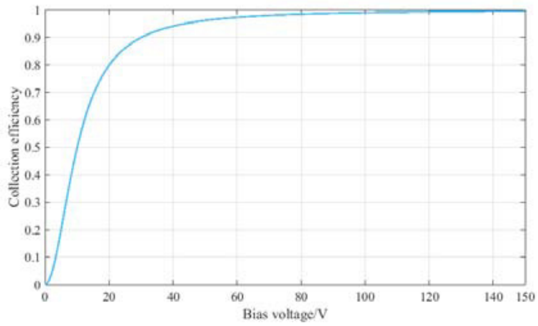

Figure 4: The collection efficiency of secondary particles.

For the 5mm air gap, the collection efficiency of secondary particles is over 99% when the bias voltage of the plate exceeds 100V.

CONCLUSION

The output characteristics of the ionization chamber is simulated and studied, the results show that the energy loss of proton beam 70-230MeV through the ionization chamber is less than 0.05%, when the air gap of two parallel plate ionization chamber are respectively 5mm, bias voltage is above 100V, the collection efficiency of secondary particles in ionization chamber can reach above 99%.The gain of the 70-230MeV proton beam in the ionization chamber is 63-145,the output current of the detector can reach the order of 10nA when the proton beam intensity is 0.1nA.

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