

CONCEPTUAL DESIGN OF A 2.45 GHz ECR ION SOURCE FOR PROTON THERAPY

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Abstract

Proton therapy has attracted increasing attention because of its favorable dose distribution enabled by its Bragg-peak behavior. Motivated by the proton therapy facility project at Shanghai Synchrotron Radiation Facility (SSRF), a 2.45 GHz ECR ion source has been designed. This paper presents the conceptual design of the prototype, together with simulation results of the magnetic field configuration, the ridged waveguide and the beam extraction.

INTRODUCTION

Ion therapy has received growing attention in recent years as an advanced radiotherapy modality. Owing to the Bragg-peak behavior, ion therapy enables highly conformal tumor irradiation while reducing the dose to surrounding healthy tissues [1]. Protons and carbon ions are the two most commonly used particles in ion therapy, while helium ions have recently attracted renewed interests as a promising intermediate option between protons and carbon ions [2]. Compared with carbon-ion therapy, proton therapy offers lower biological uncertainty and reduced nuclear fragmentation tails, making it especially suitable for pediatric treatment [3]. In addition, proton therapy facilities are more mature and cost-effective. These advantages of proton therapy motivate the development of compact and cost-effective proton therapy facilities, in which a reliable high-current proton source is an essential front-end component.

Electron cyclotron resonance ion source (ECRIS) is a type of cathode-free plasma source in which electrons are resonantly heated by microwaves under a suitable magnetic field configuration. The heated electrons subsequently ionize the working gas, producing a magnetically confined plasma from which ions could be extracted. ECR ion sources offer the advantages of long lifetime, high reliability and long-time stable operation. ECR ion sources are commonly identified by their microwave frequency. Among them, 2.45 GHz ECR ion sources have been widely used for the production of high-current singly charged ion beams, especially protons [4]. Benefiting from the mature technology, a simple structure, a low cost and high stability, 2.45 GHz ECR ion sources are well suited for the front ends of medical proton accelerator systems.

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At Shanghai Synchrotron Radiation Facility (SSRF), a full-linac proton therapy facility has been proposed as a compact and cost-effective solution for future FLASH treatment [5]. As a key component of the injector, the RFQ has been designed and an aluminium-prototype validation have been completed [6]. Under the framework of the SSRF proton therapy facility project, a 2.45 GHz ECR proton source has been designed. This paper presents the conceptual design of the ion source.

DESIGN CONSIDERATIONS AND DESIGN RESULTS

A three-dimensional engineering layout of the 2.45 GHz ECR proton source is shown in Fig. 1. The source mainly consists of the magnetic confinement system, the microwave system, the discharge chamber, and the beam extraction system. Based on this configuration, the following sections describe the detailed design of the magnetic confinement system, the microwave system and the beam extraction system.

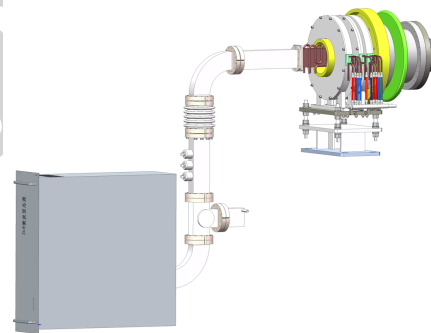


Figure 1: Layout of the 2.45 GHz ECR proton source.

Magnetic Confinement System

In this prototype, electromagnets were adopted instead of permanent magnets to realize flexible adjustment of the magnetic field and to investigate the beam performance under different magnetic field configurations. For a microwave frequency of 2.45 GHz, the corresponding ECR magnetic field is calculated as:

$$B_{ECR} = \frac{2\pi m_e f}{e} \approx \frac{f}{2.8} [kG/GHz] = 875G. \quad (1)$$

The magnetic field is generated by three solenoids, with the central solenoid carrying current in the opposite direc-

tion. The model used in Opera is shown in Fig. 2. The three-solenoid configuration offers more flexibility in magnetic field tuning. Different field configurations could be tested just by tuning the current of the central solenoid. The simulation is performed using Opera [7]. As an example (Fig. 3), three ECR resonance points are formed inside the discharge chamber, providing the electrons with more opportunities to absorb energy from the microwave and thereby helping to increase the extracted beam current.

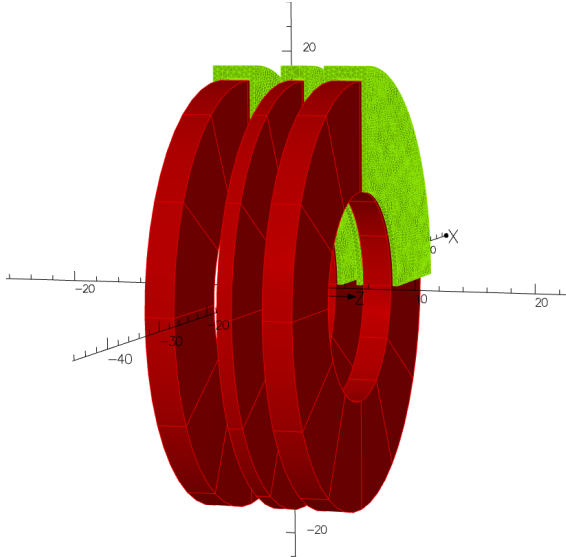


Figure 2: Model used in Opera.

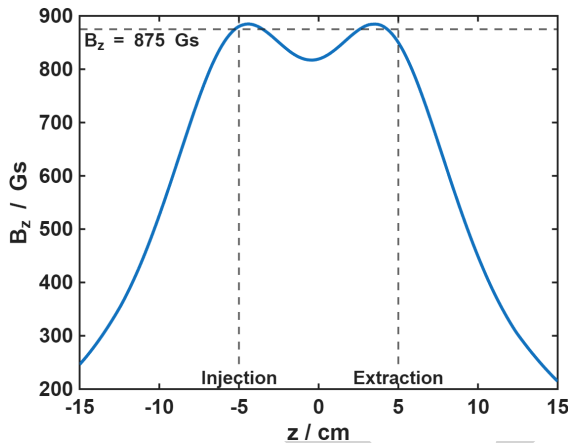


Figure 3: The magnetic field configuration.

Microwave System

The microwave system is composed of a solid-state amplifier, a circulator, a three-stub tuner, a high-voltage isolation waveguide and a ridged waveguide. The ridged waveguide is adopted for impedance matching and power-density enhancement, which facilitates plasma ignition and stable discharge. The ridged waveguide is designed and optimized with CST [8] and the model used in CST is shown in Fig. 4. Calculated result of S_{11} is shown Fig. 5. The result indicates that the microwave can be transmitted with low reflection over a wide frequency range centered 2.45 GHz, which provides tolerance for future frequency tuning experiments.

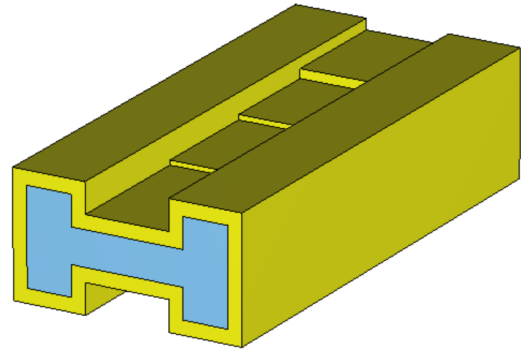


Figure 4: Model used in CST.

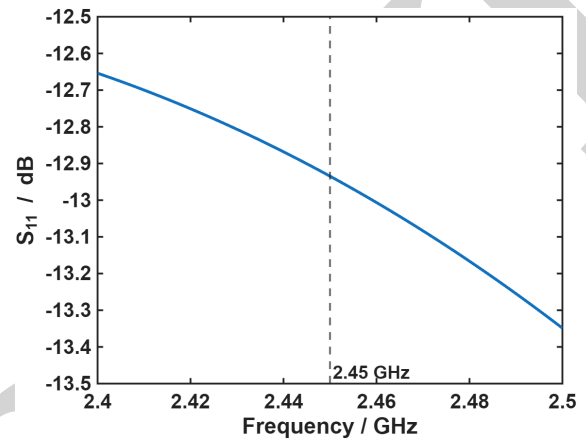


Figure 5: Simulated result of S_{11} .

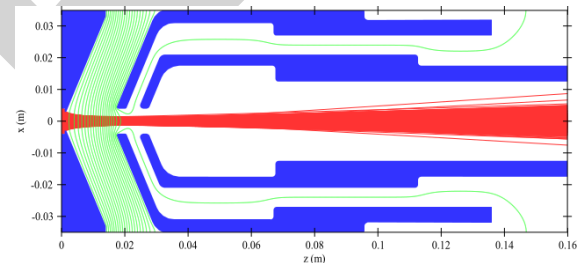


Figure 6: Simulated beam extraction using IBSimu.

Beam Extraction System

The extraction system extracts positive ions from the plasma and forms the ion beam. In this design, it consists of three electrodes: a plasma electrode biased at 35kV, a suppressor biased at -2.2kV, and a grounded electrode. The suppressor prevents the back-streaming secondary electrons from being accelerated into the plasma chamber. A Pierce-type electrode geometry with an angle of 67.5° is adopted to provide preliminary electrostatic focusing. The extraction system is designed using IBSimu [9], and simulated beam extraction result is shown in Fig. 6. The radius of the three electrodes are 3mm, 4mm, 4mm, respectively. By optimizing the positions of the electrodes, the extracted beam can be tuned to nearly parallel, which is more favorable for the subsequent beam transport. In future experiments, the rela-

tive position of the electrodes will be adjusted to control the convergence or divergence of the beam.

CONCLUSION

The conceptual design of a 2.45 GHz ECR proton source prototype has been presented in this paper. Main subsystems including the magnetic confinement system, microwave system and beam extraction system were designed and simulated. The source is currently under fabrication, and preliminary tests will be carried out after assembly. The following work will focus on magnetic field optimization, beam current measurement and improvement, and emittance measurement and optimization. The results will support further optimization of the source and the beam matching from the source through the low energy beam transfer line to the downstream RFQ.

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