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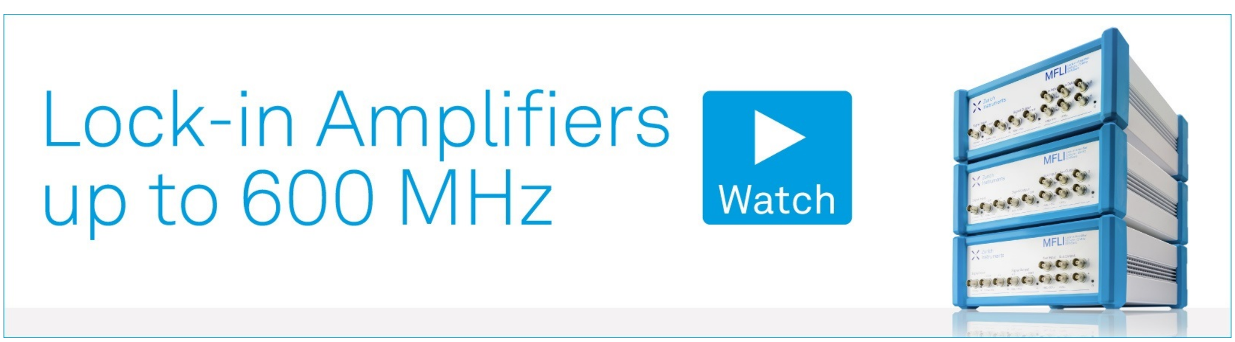

The Trajectory Simulation and Optimization of Ion Source Chimney for SC200 Cyclotron

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Abstract.SC200 is an isochronous cyclotron which generate 200 MeV, 500 nA proton for particle therapy. As an important component of the cyclotron, the ion source chimney needs to be tested and optimized. The simulation results and optimization of ion source in test bench for SC200 are described in this paper. The simulation results show that the extraction slit with different sizes and shapes has an influence on the emittance of the extraction beam. To verify the simulation results, the performance of the designed ion source chimney with optimized slits was measured, including the beam current intensity and the beam emittance.

INTRODUCTION

The SC200 superconducting proton cyclotron is designed under the collaboration of ASIPP and JINR for proton therapy. The ion source is the critical and complex component of SC200. To verify the performance of designed ion source, a test bench has been built and experiments have been done before the accelerator runs. Extraction and focusing are strongly influenced by the geometry of the extraction electrode, the plasma parameters inside the ion source chamber as well as by the ion beam spatial charge. In addition, the extracted ion current intensity and divergence of the ion beam strongly depend on construction of the ion source, size of the extraction hole, extraction voltage, etc. CST software is used for simulation of extracted particle trajectory and optimization of ion source. Following parts present the computer simulation of the ion extraction and the results of the experiments.

SIMPLIFIED THEORETICAL MODEL OF ION EXTRACTION

The simple theoretical model of an ion extraction phenomenon used in the paper is based on the Poisson equation for two flat electrodes with bias voltage V. Solving this equation provided to the so-called Langmuir–Child formula, which determines the ion current I as a function of V[1]:

$$I = \left(\frac{4\varepsilon}{9}\right)\left(\frac{2e}{m}\right)^{1/2} V^{3/2}\frac{s}{d^2} \tag{1}$$

Where ε is the dielectric constant, d is the distance between electrodes and s is the surface area that emits ions of mass m. The formula could be rewritten in the form

$$I = PV^{3/2} \tag{2}$$

where P is so called perveance coefficient, which depends mainly on the geometry of electrodes and the kind of emitted ions. As mentioned before, this model is only an approximation of an ion extraction phenomenon, and as will be presented in the paper, the $I(V)$ current–voltage dependencies obtained experimentally for real ion source, as well as numerical simulation of the extraction process, are quite

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different from those obtained from formula.

EXPERIMENTAL SET-UP

The schematic view of experimental ion source test bench that was used to measure the extracted ion beam is presented in Fig. 1.

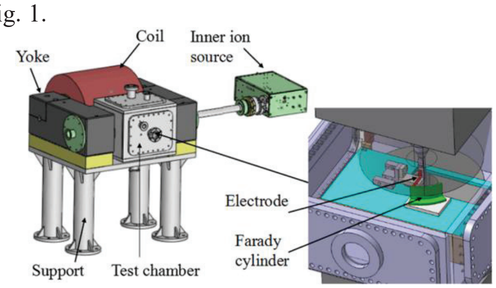
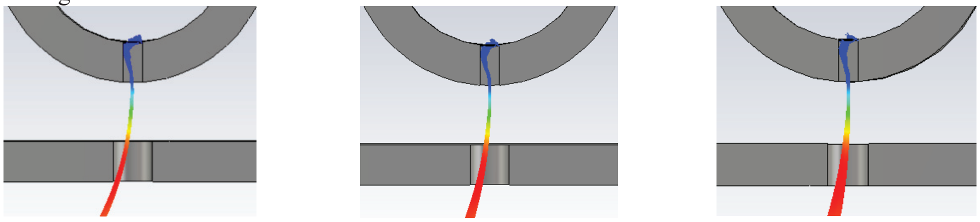


FIGURE 1. The schematic view of experimental ion source test bench.

It mainly includes coil that is capable of producing uniform magnetic fields and test chamber which the electrode and Faraday cup exist in. The beam extraction depends on the negative high voltage on the electrode. Because of space limitation, a bent copper block replaces the faraday cup to collect the extracted ion beam. Such a system enables us to measure total amount of ion current extracted from the plasma chamber of the ion source.

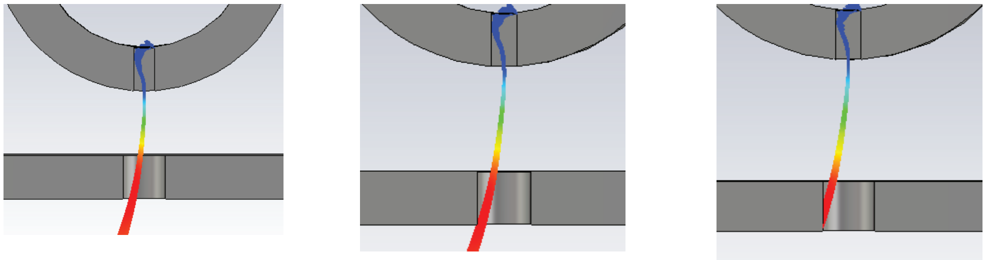
COMPUTER SIMULATION

CST code was used to simulate the extracted ion trajectory under different extraction voltage, extraction distance and size of extraction hole, etc. The model of the test bench was imported and other parameters were setting in the CST, such as magnetic field intensity, voltage and so on. The magnetic field strength as the constant parameter was set to 1T. It can be seen that the deflection radius of the beam is getting larger and the beam intensity is stronger with the increase of the extraction voltage as the Fig. 2 shows.



(a) -4 kV (b) -8 kV (c) -12 kV

FIGURE 2. Simulation results of trajectory. (a) extraction voltage is -4kV; (b) is -8kV; (c) is -12kV.



(a) 1.5 mm (b) 2 mm (c) 2.5 mm

FIGURE 3. Beam trajectories under different distances.

In Fig. 3, it presents that the beam gradually cannot pass through the slit with the increase of the distance while at the same extraction voltage. Therefore it is very important to choose a suitable distance and voltage during the experiment.

One of the key factors determining the performance of an ion source is the shape and size of the output slit in the chimney. Some simulation results are shown in Fig. 4. The beam current will be enhanced and the beam will become divergent as the slit width increases. In addition, the increase in chamber angle makes the beam easier to be extracted, but the beam divergence increases. The distance and voltage also need to be adjusted, otherwise the beam cannot pass through the slit of the electrode.

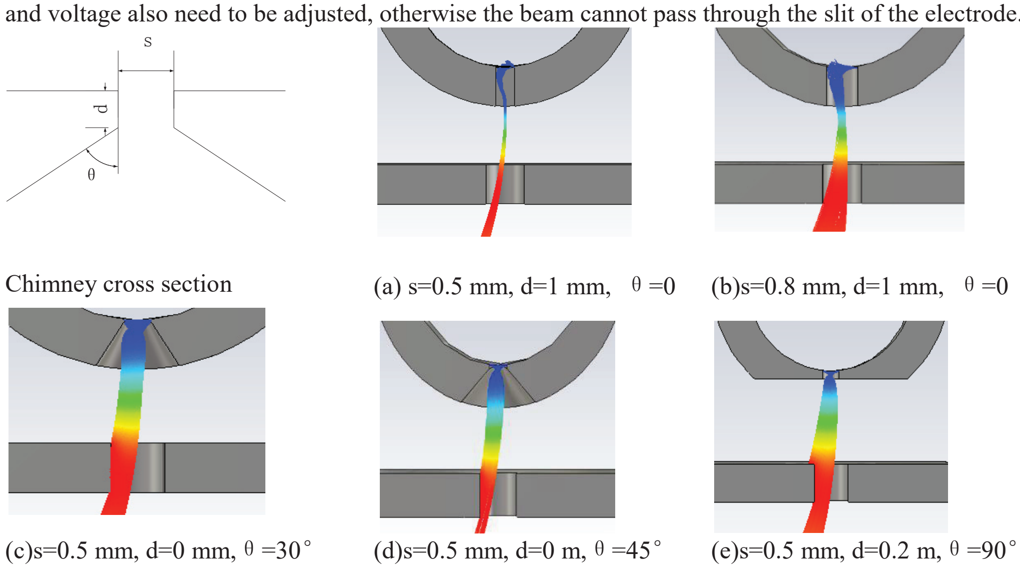


FIGURE 4. Simulation under different shape and size of the slit.

EXPERIMENTAL RESULTS

The measurements of the current–voltage dependence for the extraction process were performed for several sets of parameters describing the arc discharge in the ion source test bench. Chimney aperture shape in Fig. 4e was selected for experiment with 1.6 sccm hydrogen gas flow and Extraction current—voltage is presented in Fig. 5a. And theoretical curve $I = PV^{3/2}$ is shown in Fig. 5b. The perveance coefficient calculated from Eq. (1) for H^+ is equal to 1.8×10^{-8}[$A/V^{3/2}$].

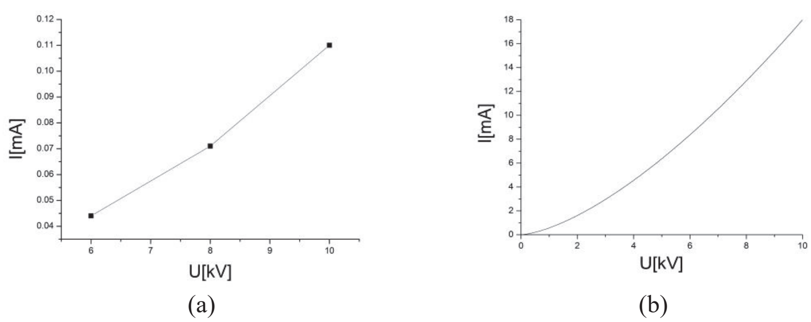


FIGURE 5. The experimental and theoretical data of the extraction ion current *I* vs. the acceleration voltage *U* dependence.

CONCLUSIONS

In the paper we present the results of computer simulation and measurements for the intensity of the hydrogen ion current emitted from the chimney as a function of extraction voltage. We also present the simulation results of different shape of chimney slit and on this basis, the slit is optimized in our test bench. We have only done preliminary experiments to verify the simulation in this paper. Next, we will do more specific and detailed experiments to validate the simulation results.

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