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RECENT PROGRESS ON ION SOURCE OF SC200 CYCLOTRON

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Abstract

A 200 MeV compact superconducting cyclotron, named SC200, for proton therapy is under development by collaboration of ASIPP (Hefei, China) and JINR (Dubna, Russia). The ion source is a significant subsystem of the cyclotron. A hot cathode internal ion source has been designed and tested for SC200 cyclotron. The ion source has been successfully arc discharged on the test bench. The extracted beam current has been measured over 100 µA and filament lifetime of ion source exceeded 100 h, which indicated that the ion source meets the design requirements. The stability of the filament under strong magnetic field has also been tested and the differences between the two kinds of filament are compared.

INTRODUCTION

Per end of 2018 more than 220000 patients have been treated worldwide with Particle Therapy. About 190000 have been treated with protons, about 28000 with C-ions and about 3500 with He, pions and other ions. Proton therapy delivers radiation to tumor tissue in a much more confined way than conventional photon therapy thus allowing the radiation oncologist to use a greater dose while still minimizing side effects. Proton beam therapy uses special machines, a cyclotron and synchrotron being the most common, to generate and accelerate protons to speeds up to 60 percent the speed of light and energies of up to 250 million electron volts. These high-energy protons are steered by magnets toward the treatment room, and then to the specific part of the body being treated. In some older proton machines, additional pieces of equipment are needed to modify the range of the protons and the shape of the beam. Newer facilities make similar adjustments by fine tuning the energy of the beam and the magnetic fields which guide their path (“pencil beam scanning” or “scanning beam”). These modifications guide the proton beam to precise locations in the body where they deliver the energy needed to destroy tumor cells. The SC200 superconducting cyclotron for hadron therapy is under development by collaboration of ASIPP (Hefei, China) and JINR (Dubna, Russia) [1]. Superconducting cyclotron SC200 will provide acceleration of protons up to 200 MeV with maximum beam current of 400 nA in 2020. Internal ion source of PIG type will be used. The Penning ion source is perfectly suitable for the accelerator, as the structure of it is simple, compact, and discharging-efficient. The penning ion source produces plasma by heating cathode which will release thermoelectron. Under the effect of arc voltage electric field, the accelerated electron will collide hydrogen, then produces plasma. The proton of plasma will be extracted and then be accelerated to form proton beam [2].

EXPERIMENTAL PROCEDURES

We established a test bed to carry out experiment so as to verify the proper functioning of ion source. The structure is shown as below Fig. 1. It includes six sections: magnet system, vacuum system, water cooling system, power system, data-collecting system and gas injection system. The magnet system consists of magnet power, coils and yoke. It can generate uniform magnet field with the maximum strength of 1 T around the arc chamber of ion source [3]. The beam extraction depends on the negative high voltage on the electrode. The beam extraction electrode was fixed outside the ion source by ceramic insulation, and the gap between the electrode and the ion source is kept at approximately 2 mm. The extraction electrode slit size is 4.3 mm × 1 mm with a 1 mm thickness. 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. On this ion source test bench, a lot of ion source performance tests have been done, including the selection of ion source discharge parameters, the relationship between ion source discharge capacity and gas flow, arc voltage and other factors.

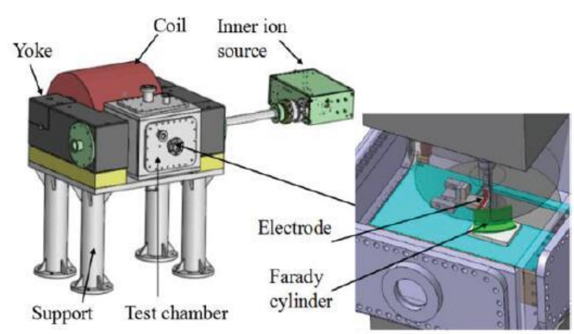

Figure 1: The components of the ion source test bench.

In order to verify that the filament can also maintain good performance in the central region of the SC200 cyclotron, we went to the high magnetic field laboratory of the Chinese Academy of Science and carried out repeated experiments under the 3T magnetic field generated by their equipment. The specific conditions of the device are shown in Fig. 2.

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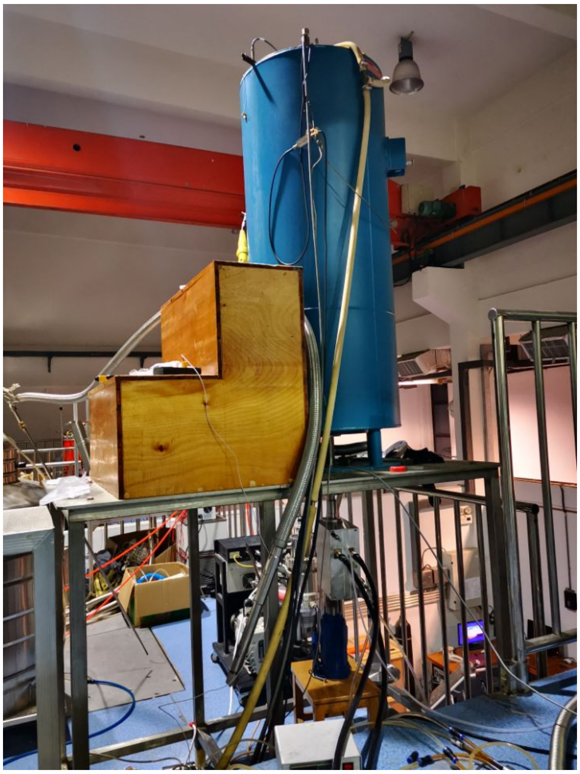

Figure 2: The test bench in the high magnetic field laboratory of the Chinese Academy of Science.

In addition, experiments have been carried out for filament with different materials and shapes. Figure 3 shows two different filaments, the difference being the thickness at the bottom which is to increase the mechanical properties of the filament. Experiments are also needed to verify the discharge capacity of the two types of filament.

Figure 3: Thin filament and thick filament.

RESULT AND DISCUSSION

Figure 4 shows the value and variation trend of the measured arc current under different filament current. The other general conditions were: gas flow 2 sccm, magnetic field 1 T and arc voltage 170 V. A thick filament requires a larger filament current to produce the same amount of arc current as a thin filament. With the increase of filament current, arc current rises rapidly in both thick filament and thin filament.

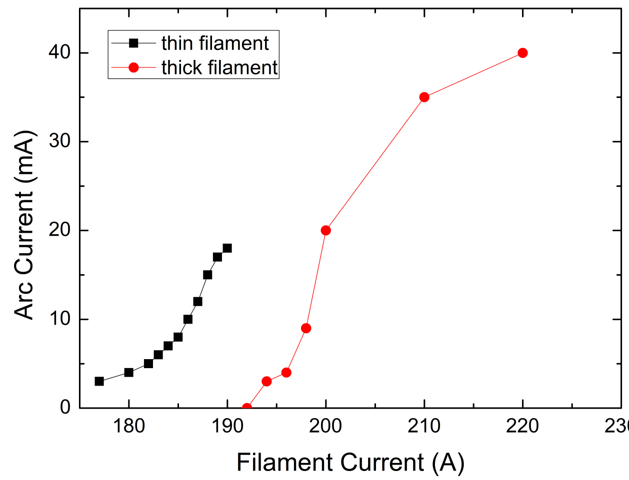

Figure 4: Arc current versus filament current.

The extracted beam intensity at various extraction voltage was measured under a magnetic field of 1 T, an arc voltage of 170 V and a gas flow of 2 sccm. The results are shown in Fig. 5. The thin filament current is set to 175 A, while the thick filament current is set to 215 A. With a current of more than 100 μA, we chose the thin filament as the final filament of our ion source, which will reduce the load on the filament power supply.In addition, high current will cause permanent damage to the filament and more easily cause the filament to break, as shown in Fig. 6.

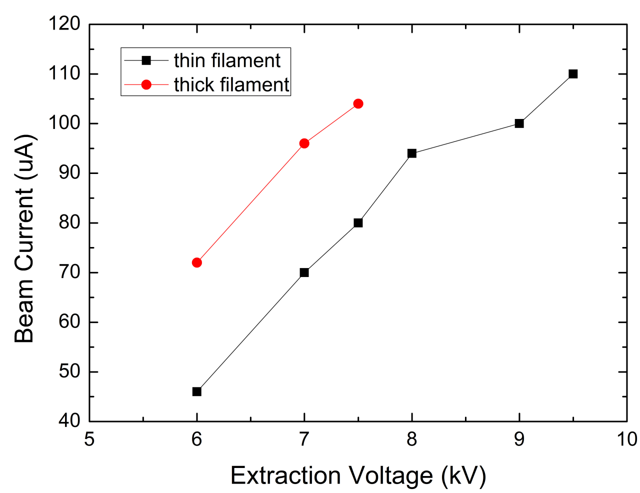

Figure 5: Results of beam extraction experiments of thin filament: beam current versus dc extraction voltage.

In addition, we did a long time stability test on the thin filament to verify whether it can meet the stable work in a treatment cycle. Figure 7 shows that the discharge is extremely stable for 1 h and the beam extraction for 0.5 h. The beam extraction strength exceeds the accelerator requirement of 100 μA.

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Figure 6: Fracture of thick filament at high current.

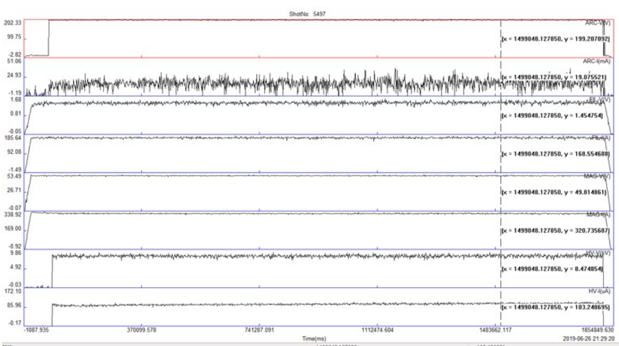

Figure 7: Waveform collected of the stable ion source discharge.

CONCLUSION

The hot cathode Penning inner ion source plays a very important role for the whole proton superconducting cyclotron system. The results obtained on our test bench confirm that the structure and operation state of the designed ion source is suitable for long pulses at high beam current. Thin filament can well meet the design requirements of the SC200 cyclotron. After extensive testing, the ion source is capable of generating beams of more than 100 µA and of stable operation for a long time. The integrated commissioning of the SC200 cyclotron will begin at the end of this year. The ion source will then be tested with other subsystems.

ACKNOWLEDGEMENTS

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REFERENCES

[1] G. A. Karamysheva *et al.*, "Compact superconducting cyclotron SC200 for proton therapy", in *Proc. 21th Int. Conf. on Cyclotrons and their Applications (Cyclotrons'16)*, Zurich, Switzerland, Sep. 2016, pp. 371–373. doi:10.18429/JACoW-Cyclotrons2016-THC03

[2] J. R. J. Bennett, "A review of PIG sources for multiply charged heavy ions", *IEEE Trans. Nucl. Sci*, vol. 19, pp. 48-68, Apr. 1972. doi:10.1109/TNS.1972.4326630

[3] Gen Chen *et al.*, "The construction of the inner ion source for SC200 compact superconducting cyclotron", *AIP Conference Proceedings*, vol. 2011, p. 090009, Sep. 2018. doi:10.1063/1.5053390