Preliminary design and simulation results of a Ne\textsuperscript{+} beam source

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Abstract. An ion source with Ne beam was designed to provide fast ions for basic physical research in the Institute of Plasma Physics, Chinese Academy of Science (ASIPP). The ion source was designed with hot cathode plasma source and three electrodes accelerator. The designed beam energy is 10-20 keV with beam size of 250 mm × 250 mm. The designed beam power is 50 kW with beam duration of 2 seconds. The extracted beam current and beam divergence angle was simulated to estimate the beam parameters with beam energy of 10 keV and 20 keV. The details of simulation results and the design of source was presented in this paper.

1. Introduction

In order to support the basic physical research in Institute of Plasma Physics, Chinese Academy of Sciences (ASIPP), an ion beam system was designed to supply fast ions. The desired parameters of fast ions are beam energy is 10-20 keV, beam power is 50 kW and beam duration is 2 seconds. A Ne\textsuperscript{+} beam system was designed based on the R&D experiences of neutral beam injector for the Experimental Advanced Superconducting Tokamak (EAST)[1-7].

The ion beam system contains a Ne\textsuperscript{+} beam source, vacuum vessel, calorimeter, power supply system, water cooling system, control system and gas pumping system. The performance of ion beam of Ne\textsuperscript{+} beam source was simulated. The detail design of Ne\textsuperscript{+} beam was also presented.

2. The Ne\textsuperscript{+} beam source

The Ne\textsuperscript{+} beam source contains a hot cathode plasma generator and an accelerator with three electrodes. The schematic diagram of beam source is shown in the Fig. 1. The designed parameters of the beam source are shown in the Table 1. The plasma generator has a rectangle cross section arc chamber with dimension of 400 mm × 400 mm × 300 mm (W×L×H). There are three lines of permanent magnets installed on the back electron dump plate and 36 lines on the arc chamber body to form axial line-cusp configuration. Each Sm-Co permanent magnet has the magnet intensity of 3500G, and can form a large magnetic-free-area region to generate plasma. In the opposite direction of accelerate grids, 16 filaments are installed near the back electron plate, which to provide sufficient primary electrons. The filaments are made of pure tungsten with hairpin shape and each of them is 160 mm long with the diameter of 1.5 mm. The slit-type grids are apply on the accelerator system, which have the transparence of 60%.
Figure 1. Schematic diagram of high current ion source

Table 1. The designed parameters of beam source

| Items                       | Specifications            |
|-----------------------------|---------------------------|
| Source Species              | Ne$^+$                    |
| Source type                 | Hot cathode               |
| Beam energy                 | 10-20keV                  |
| Beam power                  | 50 kW                     |
| Beam duration               | 2 s                       |
| Beam cross section          | 250 mm × 250 mm           |
| Number of accelerator       | 3                         |
| Extraction sort             | Multi-slot                |
| Transparence                | 60 %                      |
| Divergence angle            | Less than 5°              |

Figure 2. Schematic diagram of accelerator for the Ne$^+$ beam source
3. The accelerator of beam source

The accelerator is slot-type grids with three layers, which are plasma grid, suppressor grid and exit grid, which is shown in the Fig. 2. Each layer has two modules, and each module have 14 rails, which made of molybdenum. The plasma grid and exit grid are circular cross type with diameter of 3.6 mm. The gradient grid is water-drop cross type with width of 4.57 mm and depth of 5.99 mm. The distance between two rails is 5.4 mm. The gap between plamsa grid and suppressor grid is 10.67 mm, between guppressor grid and exit grid is 1.73 mm. The extraction area is confine in 250 mm × 250mm with the mask plate.

The performances of beam source, such as beam divergence angle, extracted beam current, beam profile are simulated. The simulation picture of accelerator grids is shown in the Fig. 2 too.

4. Simulation results of Ne⁺ ion source

The beam divergence angle and beam power were simulated with different beam energy of 10 keV and 20 keV. The results are shown in the Fig. 3 and Fig. 4, respectively. It can be seen from Fig. 3 that the beam power increased from 15 kW to 40 kW and the beam divergence angle less than 5 degree. The beam power is about 27 kW with the optimum beam divergence angle of 2.25 degree. But the beam power can’t achieves 50 kW.

The Fig. 4 tells us the parameters of beam with beam energy of 20 keV. The beam power increased from 85 kW to 188 kW when the beam divergence angle changed between 2.25 to 2.25 degree. The beam power is about 130 kW with the optimum beam divergence angle of 2.25 degree. The beam power with beam energy of 20 keV is much higher than the beam with beam energy of 10 keV, which can meets the requirement of beam power of 50 kW.

![Figure 3](image_url)

**Figure 3.** The beam power and beam divergence angle as a function of ion density (10 keV)
Consider the beam divergence angle is very large, the beam profile during the beam transmission was simulated to estimate the injected beam power. In order to decrease the beam divergence angle, the beam extract surface was simulated with two structures, which is shown in the Fig. 5. The left one is the two pieces of grids are arranged in the same plane, and the right one is the two pieces of grids are arranged with angle of 1 degree, which can forms the mechanical focus.

The ion beam system was designed with length of 150 cm and the beam will injected into the plasma about 180 cm downstream from the exit grids. The beam profiles in the position of 50 cm, 100 cm, 150 cm and 180 cm downstream the exit grid were simulated with two structures. The results are shown in the Fig. 6 and Fig. 7. It can been seen from the Fig. 6 that, the beam power profile is much smooth during the beam transmission, it is good to achieve uniform beam power. But the beam power is not uniform when the accelerator has a angle, which is shown in the Fig. 7. The beam is overlaped and like Gaussian distribution. The power density in the middle of beam is about two times compare with it in the margin of beam. So, the beam loss is smaller compare with the accelerator with flat structure. The beam transmission efficiency with minimum divergence angle of 2.25 degree and beam energy of 20 keV is simulated and shown in the Fig. 8. When the beam transmitted into the plasma, the beam transmission efficiency is estimated about 88% for flat accelerator and about 93% for the accelerator with angle.
Figure 6. Beam profiles in different positions with flat accelerator grid arrangement

Figure 7. Beam profiles in different positions when the accelerator grids have angle

Figure 8. Beam transmission efficiency with two different structures
5. **Structure design of accelerator for Ne⁺ ion source**

Three layers of accelerator were employed. Each layer of accelerator has the same structure with two modules, contains grids, holds, grids support, side plate and water cooling pipes, which shown in the Fig. 9. Two modules are installed on the grids support and can be adjusted to flat or with an angle. The cooling water goes through the cooling pipes and the inner pipe of each grids to takes away the heat deposited on the grids.

![Structure of accelerator for Ne⁺ beam source](image)

**Figure 9.** Structure of accelerator for Ne⁺ beam source

6. **Conclusion**

An Ne⁺ ion source with hot cathode plasma generator and three electrodes accelerator is designed to supply the fast ions for basic physical research. The beam power, beam divergence angle and beam transmission efficiency were simulated with beam energy of 10 keV and 20 keV to estimate the beam performance. The results shown that the maximum beam power of 40 kW with beam energy of 10 keV when the divergence angle less than 5 degrees. The beam power of 28 kW and 130 kW can be extracted with the beam energy of 10 keV and 20 keV and the beam has the minimum divergence angle of 2.25 degrees. The divergence angle can be decreased by fold the accelerator grids, and the beam transmission efficiency also increased. The design of Ne⁺ ion source can meet the requirements of supplying fast ions.

**References**

[1] Y. X. Wan, J. G. Li and P. D. Weng, “First engineering commissioning of EAST tokamak”, Plasma. Sci. Technol. 8, 253 (2006).
[2] C. D. Hu and NBI Team, “Conceptual Design of Neutral Beam Injection System for EAST”, Plasma Sci. Technol. 14, 567 (2012).
[3] Y. H. Xie, C. D. Hu, S. Liu, Y. L. Xie, Y. J. Xu, L. Z. Liang, C. C. Jiang, P. Sheng, Y.M. Gu, J. Li, Z. M. Liu, “R&D progress of high power ion source on EAST-NBI”, Plasma. Sci. Technol. 13, 541 (2011).
[4] C. D. Hu, Y. H. Xie and NBI Team, “The Development of a Megawatt-Level High Current Ion Source”, Plasma Sci. Technol. 14, 75 (2012).
[5] C. D. Hu, Y. H. Xie, S. Liu, Y. L. Xie, C. C. Jiang, S. H. Song, J. Li and Z. M. Liu, “First plasma of megawatt high current ion source for neutral beam injector of the experimental advanced superconducting tokamak on the test bed”, Rev. Sci. Instrum. 82, 023303 (2011).
[6] Y. H. Xie, C. D. Hu, S. Liu, J. Li, Y.J. Xu, Y.Q. Chen, L.Z. Liang, Y.L. Xie, C.C. Jiang, P. Sheng, Z.M. Liu, “Upgrade of accelerator of high current ion source for EAST neutral beam injector”, Fusion Eng. Des., 100, 265(2015)
[7] Y.H. Xie, C.D. Hu, H. W. Zhao, NBI Team. “Analysis of ion beam optics of tetrode accelerator for neutral beam injector on the experimental advanced superconducting Tokamak”, Nucl. Instrum. Meth. A, 791, 22 (2015).