ISBN: 978-3-95450-203-5 doi:10.18429/JACoW-HIAT2018-THODA01

PRELIMINARY DESIGN AND SIMULATION RESULTS OF Ne^+ BEAM SOURCE*

Y. H. Xie#, C. D. Hu, Y. J. Xu, J. Li, Y. L. Xie,
Institute of Plasma Physics, Chinese Academy of Sciences, 230031 Hefei, China

Abstract

An ion source of Ne beam was designed 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 with three electrodes accelerator. The designed beam energy is 10-20 keV, the beam power is 50 kW, beam size is 250 mm × 250 mm and beam duration is 2 seconds. The three electrodes accelerator with slit type was designed. The extracted beam current and beam divergence angle was simulated. The maximum beam power of 40 kW can be extracted when the divergence angle less than 5 degree with beam energy of 10 keV and the beam power of 28 kW can be extracted with minimum divergence angle of 2.2 degree. When the beam energy is 20 keV, the maximum beam power of 180 kW can be extracted when divergence angle less than 5 degree. And the beam power is 130 kW with minimum beam divergence angle is 2.2 degree too. The results shown that, the maximum beam power can't got 50 kW with beam energy of 10 kW, but the beam power can achieve 130 kW with beam energy of 20 keV.

INTRODUCTION

In order to support the basic physical research in Institute of Plasma Physics, Chinese Academy of Sciences (ASIPP), a fast ion source was needed. The desired fast ions with beam energy of 10-20 keV, beam power of 50 kW with beam duration of 2 seconds. A Ne^+ beam system was designed based on the R&D experiences of high power neutral beam injector on Experimental Advanced Superconducting Tokamak (EAST) [1-7].

The ion beam system contains a Ne^+ beam source, vacuum vessel, calorimeter, power supply system, water cooling system, control system and gas pumping system. The Ne^+ beam source was designed and the beam performance was simulated. The preliminary simulation results were presented in this manuscript.

THE Ne^+ BEAM SOURCE

The Ne^+ beam source contains a hot cathode plasma generator and an accelerator with three electrodes. The schematic map of beam source is shown in Fig. 1. The designed parameters of the beam source are shown in 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 pure tungsten 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 multiple slit type apertures are used in the accelerator system, which have the transparence of 60%. Each layer of the two accelerator grids have 28 rails, which has cavity structure and made of molybdenum.

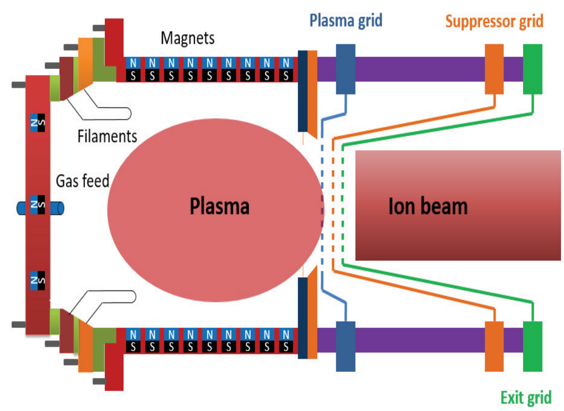

Figure 1: Schematic of high current ion source.

Table 1: The Designed Parameters of Beam Source

Source Species	Ne^+
Source type	Hot cathode
Beam energy	10-20keV
Beam power	50 kW
Beam duration	2s
Beam cross section	250 mm × 250 mm
Number of accelerator	3
Extraction sort	Multi-slot
Transparence	0.6
Divergence angle	Less than 5°

*Work supported by National Natural Science Foundation of China (Contract No. 11675215, 11575240,11675216)
#xieyh@ipp.ac.cn

ISBN: 978-3-95450-203-5 doi:10.18429/JACoW-HIAT2018-THODA01

THE ACCELERATOR OF BEAM SOURCE

The accelerator system is slot type and has a three stage electrode grids, which are plasma grid, suppressor grid and exit grid, which is shown in Fig. 2. Each stage has two modules, and each module has 14 rails and which is 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 and the accelerator has a beam transparency of 60% . 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.

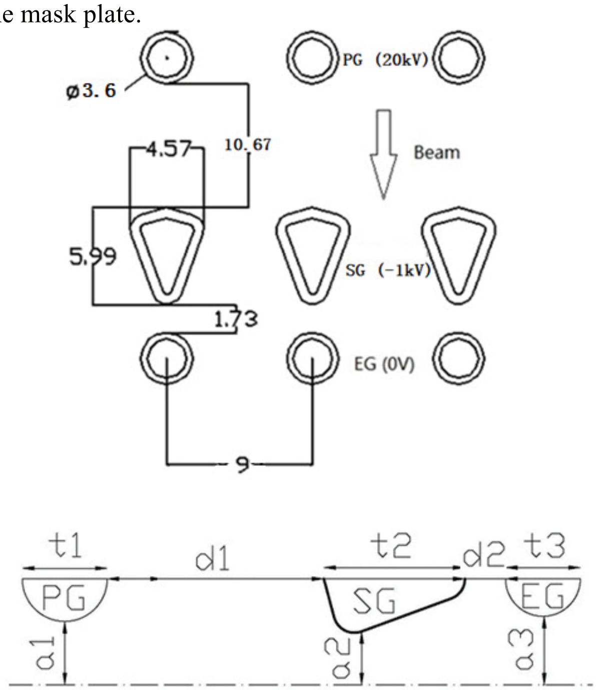

Figure 2: Schematic map of accelerator for the Ne· beam source.

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 Fig. 2 too.

PRELIMITARY SIMULATION RESULTS OF BEAM 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 Fig. 3 and Fig. 4, respecitely. From Fig. 3, it can be seen that, the beam power increased from 15 kW to 40 kW with the beam divergence angle less than 5 degree. The beam power is around 27 kW when the beam in the optimum beam divergenc angle of 2.25 degree. The results also shown that, the beam power can not achieve 50 kW with beam energy of 10 keV.

The Fig. 4 tells us the beam power with different divergence angle with beam energy of 20 keV. The beam power increased from 85 kW to 188 kW when the beam divergence angle changed from 5 degree to 2.25 degree and then 5 degree too. The beam power is much larger than the beam with 10 keV, which can meets the requirement of 50 kW extracted beam power. The beam power is around 130 kW with the optimum beam divergence angle of 2.25 degree.

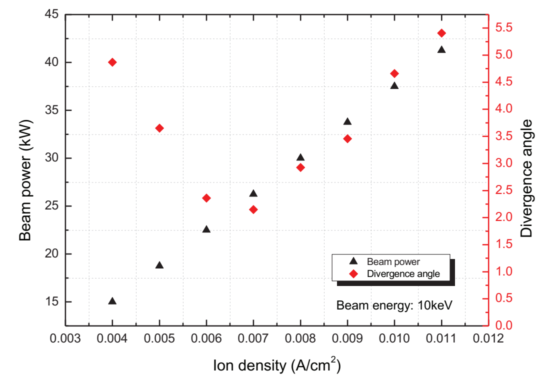

Figure 3: The beam power and beam divergence angle as a function of ion density with beam energy of 10 keV.

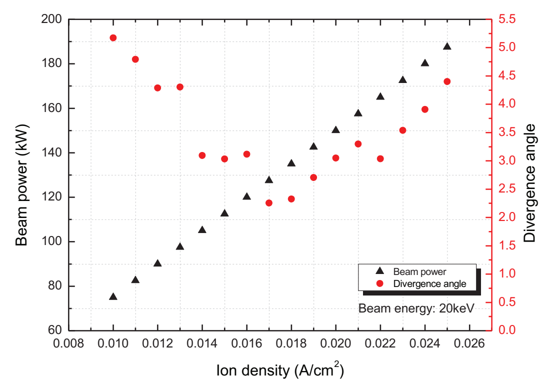

Figure 4: The beam power and beam divergence angle as a function of ion density with beam energy of 20 keV.

Consider the beam divergence angle is very high, the beam profile during the beam transmission was simulated too. In order to decrease the beam divergence angle, the beam extract surface was simulated with two tructures, which is shown in 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 form the mechanical focus.

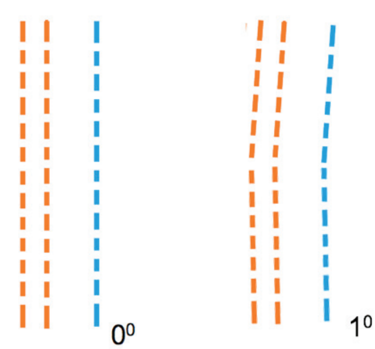

Figure 5: Layout of two pieces of accelerator.

ISBN: 978-3-95450-203-5 doi:10.18429/JACoW-HIAT2018-THODA01

The beam system was desgined with length of 150 cm and the beam will injected into the plasma in the position of 180 cm. 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 Fig. 6 and Fig. 7. It can been seen from Fig. 6 that, the beam power profile is much smooth during the beam transmission, it is good to achieve uniform beam power among the beam extraction area. But the beam power is not uniform when the accelerator has a angle, which is shown in Fig. 7. The beam is overlaped and like Gaussian distribution. The power density in the middle is about two times conpare with it in the mergin of beam. In this case, the beam loss is smaller compare with the accelerator with flat sturcture. The beam transmission efficiency with minimum divergence angle of 2.25 degree and beam energy of 20 keV is simulated and shown in Fig. 8. When the beam transmited into the plasma, the beam transmission efficiency is estimated about 88% for flat accelerator and about 93% for the accelerator with angle.

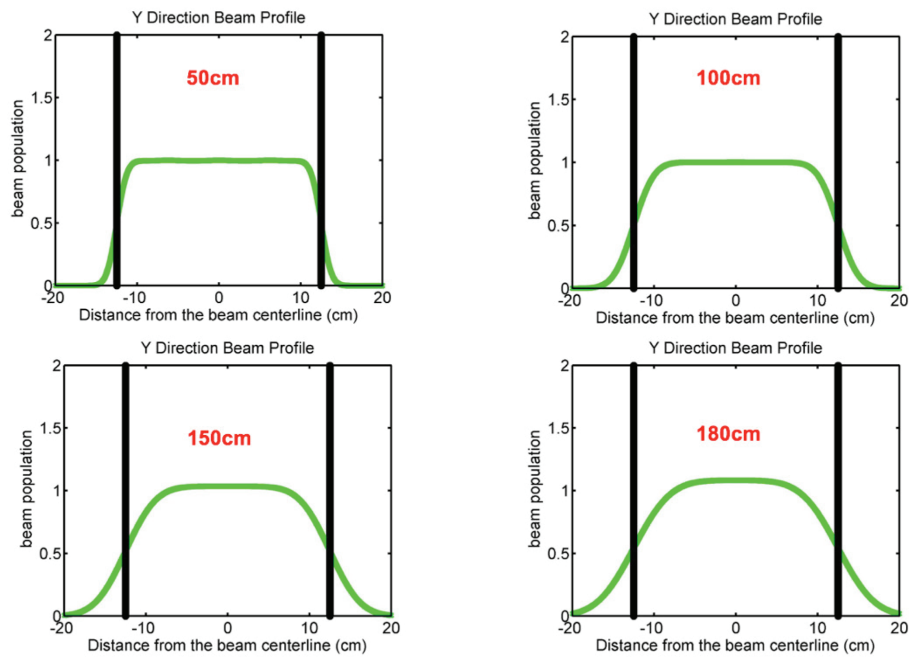

Figure 6: Beam profiles in differernt postions when accelerator grid arranged in the same plane.

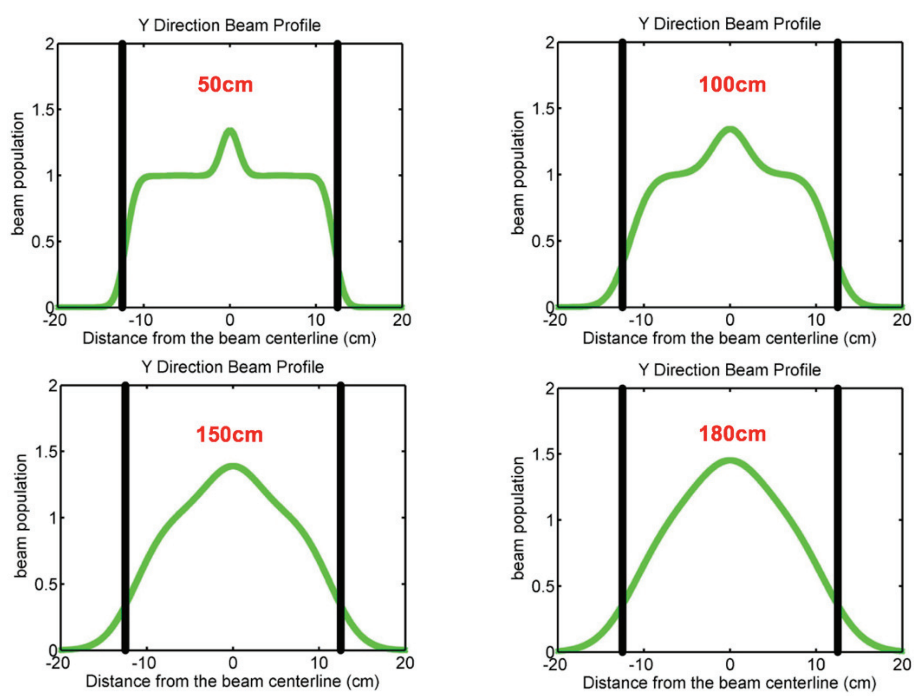

Figure 7: Beam profiles in differernt postions when the accelerator grids arranged with angle of 1 degree.

ISBN: 978-3-95450-203-5 doi:10.18429/JACoW-HIAT2018-THODA01

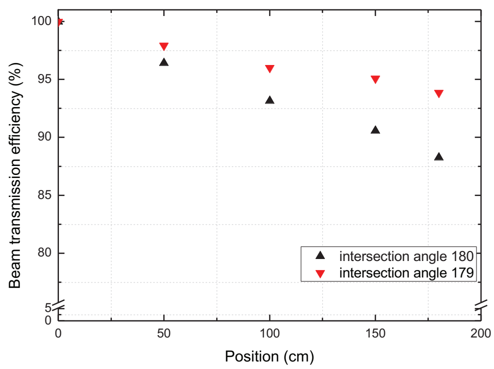

Figure 8: Beam transmission efficiency with two different structures.

STRUCTURE DESIGN OF ACCELERATOR FOR NE$^+$ BEAM SOURCE

The three layers of accelerator has the same sturcture. Each layer of accelerator contains grids, holds, gird support, side plate and water cooling pipes, which shown in Fig. 9. The module of grids is installed on the grid suport can be adjusted to to flat or has a angle. The cooling water is connected with the cooling pipes and goes through the inner pipe of each grid, which can takes away the heat deposited on the grids.

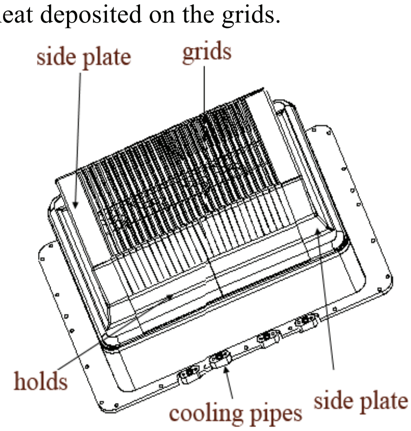

Figure 9: Structure of accelerator for Ne$^+$ beam source.

CONCLUSION

An Ne$^+$ beam source with hot cathode plasma generator and three electrodes accelerator is designed to supply the fast ions for basic physical research. The designed beam power is 50 kW and beam cross section is 250 mm × 250 mm. The beam energy was designed from 10 keV to 20 keV.

The beam divergence angle, beam power and beam profiles were simulated with beam energy of 10 keV and 20 keV. The results shown that the maximum beam power of 40 kW and 180 kW can be extracted when the divergence angle less than 5 degree with beam energy of 10 keV and 20 keV, respectively. The beam power is 28 kW and 130 kW can be extracted with minimum divergence angle of 2.25 degree when the beam energy is 10 keV and 20 keV, respectively. The divergence angle can be decreased by fold the accelerator grids. But the beam power density will change to Gaussian distribution.

Under this design, the maximum beam power can not achieve 50 kW with beam energy of 10 kW, but the beam power can achieve 130 kW with beam energy of 20 keV.

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).