

PROGRESS OF DEVELOPMENT OF 4 MW HIGH POWER ION SOURCE FOR THE EAST NEUTRAL BEAM INJECTOR*

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Abstract

A 4 MW high Power ion source is developed for the Experimental Advanced Superconducting Tokamak (EAST) neutral beam injector (NBI), which is used to auxiliary plasma heating and current drive. The ion source is designed to generate a deuterium ion beam of 2-4MW with energy of 50-80 keV, the beam duration is 10-100 seconds. The ion source consists of the multi-cusp bucket plasma generator and tetrode accelerator with multi-slot apertures. The plasma generator has a rectangular shape arc chamber. 32 pure tungsten filaments installed in the long side of arc chamber to supply primary thermo-electrons. A multi-slot type of accelerator is used on the EAST NBI ion source. It consists of plasma grid (PG), gradient grid (GG), suppressor grid (SG) and exit grid (EG). Each grid has 64 rails which are made of molybdenum. The beam extraction area is 120mm * 480mm, and has a transparency of 60 %. The ion source is tested on the test bed in the ASIPP. The hydrogen beam power of 4MW with beam energy of 80 keV in 1 second and long pulse of 100 seconds with beam energy of 50 keV and beam current of 33A are achieved on the test stand respectively.

INTRODUCTION

The Experimental Advanced Superconducting Tokamak (EAST) is one of the fully superconducting tokamak, its aim at the long-pulse operation (1000s) to study the physics of steady-state operation for nuclear fusion sciences[1]. In order to heating and driving the EAST plasma, a Neutral Beam Injection (NBI) system is designed and developed in the Institute of Plasma Physics, Chinese Academy of Sciences (ASIPP)[2-5]. A NBI system compares two ion sources, which have the same structure and designed parameters. According to the physical requirements of the EAST, a hot cathode multi-cusp ion source with four stage accelerator grids is developed and tested in the year of 2010. Through several campaigns of ion source tests, three ion sources are developed and tested in the ion source test bad. In September of 2013, one beam line with two ion sources are installed on the EAST and high power neutral beam with 2MW are injected into EAST in July of 2014. In the same time, a modified ion source with diamond accelerator are developed and tested. It will contribute in the next campaign experiment of the EAST in 2014.

THE HIGH POWER ION SOURCE FOR EAST-NBI

The hot cathode ion source with tetrode accelerator is employed for the EAST-NBI system[6-7]. The schematic map of ion source is shown in Figure 1. The designed parameters of the ion source are shown in Table 1. The plasma generator has a rectangle cross section arc chamber with dimension of 650 mm × 260 mm × 300 mm (W×L×H). There are three lines of permanent magnets installed on the back electron dump plate and 40 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, 32 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 four accelerator grids have 64 rails, which has cavity structure and made of molybdenum. The cooling water runs through the inner of rails, so, it has good performance of heating remove.

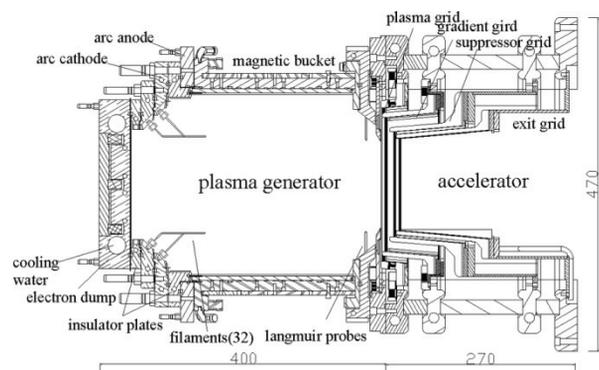


Figure 1: Schematic of high current ion source.

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Table 1: The Main Designed Parameters of Ion Source

Source Sort	Bucket Ion Source
Number of Filaments	32
Beam energy	50-80keV
Beam power	2-4MW
Beam duration	10-100s
Beam cross section	120mm*480mm
Number of accelerator	4
Extraction sort	Multi-slot
Transparence	0.6
Divergence angle	X:0.6°, Y:1.2°

THE ACCELERATOR FOR EAST-NBI

The accelerator system is slot type and has a four stage electrode grids, which are plasma grid, gradient grid, suppressor grid and exit grid, which is shown in Figure 2. Each stage has four modules, and each module has 14 rails and which is made of molybdenum. The gradient grid is water-drop cross type and the other three are circular cross type. The extraction area is confine in 100 mm × 480mm with the mask plate, so the ions can be extracted by 53 slot apertures with distance of 5.4 mm. The accelerator has a high beam transparency of 60%. The cooling water goes through the inner pipe of rails to remove the heating deposition. In order to improve the ion extraction efficiency, the plasma grids are changed from circular cross section to diamond cross section, which can be seen in Figure 2. The distance of each slot aperture is the same, the thickness is decreased from 3.6 mm to 2.81mm. The shape of the grids is also changed to the benefit of got high performance ion beam with lower divergence angle. A picture of assembled accelerator grids is shown in Figure 3.

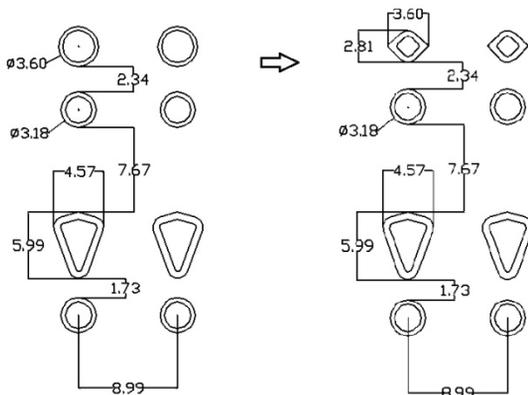


Figure 2: Schematic map of accelerator for the high current ion source.

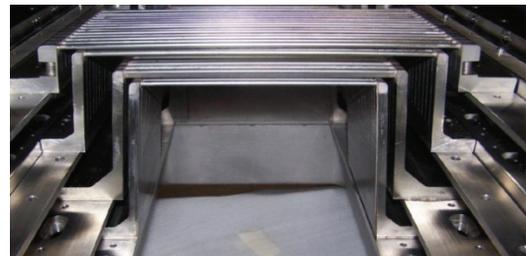


Figure 3: Picture of accelerator with four stages of grids.

PERFORMANCE OF ION SOURCE ON THE TEST BED

The ion source with circular and diamond cross section grids are tested on the ion source test bed. The arc chamber has the same tructure, and the plasma generated in the arc chamber will have the same parameters. The high arc current of 400A can be achieved when the filaments voltage large than 7.5 V and the maxium arc power can reaches 100 kW.

The hydrogen ion extraction tested with two type of accelerator. The extracted ion beam with diamond grids is 55A with beam energy of 80keV, which is larger than the circular grids.

Beam perveance ($\text{perv} = A/V^{3/2} * 10^6$, A: beam current [A], V: applied beam voltage [V]) is the other parameter to estimate the ability of ion source, and the ion extraction ability too. The experimental results of beam perveance for the diamond and circular grid are shown in Figure 4. The ion source with diamond grid has high beam perveance of 2.8 uperv, and the circular grid is about 2.4 uperv. The beam divergence angle also measured in the experiment. For the diamond grid, the divergence angle is 1.4 degree with optimum beam perveance of 2.75 uperv. The divergence angle is 1.8 degree with optimum beam perveance of 2.3 uperv, which can be seen in Figure 5. The results tells that, the ion source with diamond grid has lower divergence angle and higher beam perveance. It can improve the ability of ion source for high beam power. Further more, lower beam divergence angle can decrease the beam power deposition on the collimator and help for the long pulse operation of ion source.

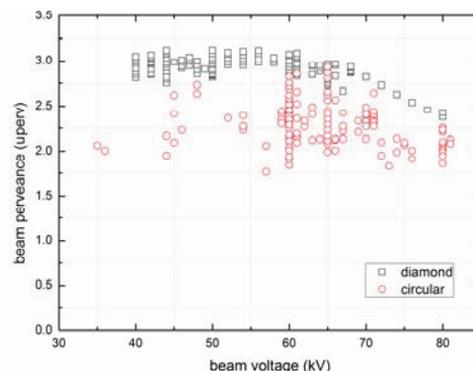


Figure 4: Beam perveance as a function of beam voltage with different type of plasma grids.

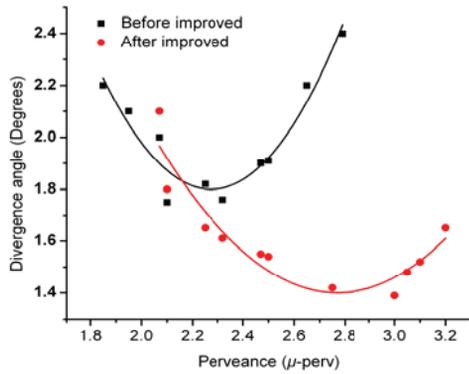


Figure 5: Divergence angle as a function of perveance with circular and diamond grids.

The operation of ion source with long pulse is the physical request of the EAST. In order to get long pulse operation of high current ion source, the arc regulation technology[8] and beam modulation technology are employed. The arc regulation is used to use the plasma density to feedback control the arc power output on the ion source and the ion source can be operated much more stably to realize long pulse operation. The long pulse of 100 s hydrogen beam is extracted on the test bed, which is shown in Figure 6. The extracted beam energy is 50keV with beam current of 33A. The modulation frequency is 2Hz with a duty cycle of 15%.

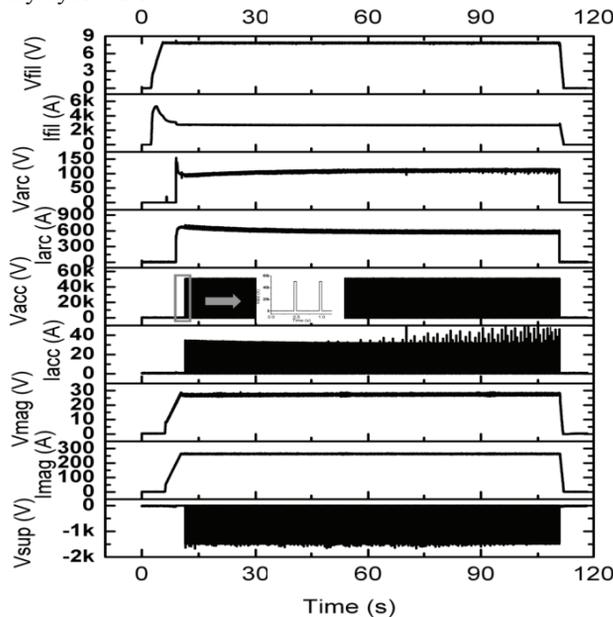


Figure 6: Long pulse ion beam extraction of 100s with beam energy of 50 keV and beam current of 33 A.

NEUTRAL BEAM INJECTION ON EAST

The first beam line with two ion sources is installed on the EAST. The deuterium beam is extracted and injected into the EAST with a neutral beam power of 2MW. The two ion sources can be operated individually and together, which depends on the operation mode of EAST. In the future, the second beam line with two upgraded ion sources will be installed on the EAST, and the high power neutral beam will be injected in the next campaign of experiment.

CONCLUSION

The high current ion sources have been developed and tested on the test bed. The beam energy reaches 80 keV, and beam power reaches 4MW. The long pulse of 100 s is achieved with the arc regulation technology and beam modulation technology. The new ion sources with diamond cross section have been developed and tested too. The results show that the new ion source has a lower divergence angle with a higher optimum perveance. Two ion sources are installed on the EAST-NBI system, the joint operation of the two ion sources is tested and 2MW neutral beam is injected into the EAST tokamak. In the future, the beam line two will be installed on EAST with upgraded ion sources.

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