A Multi-megawatt Long Pulse Ion Source of Neutral Beam Injector for the KSTAR

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Abstract

A multi-megawatt long pulse ion source (LPIS) of neutral beam injector was developed for the KSTAR. Beam extraction experiments of the LPIS were carried out at the neutral beam test stand (NBTS). Design requirements for the ion source were 120 kV/65 A deuterium beam and a 300 s pulse length. A maximum ion density of $9.13 10^{11}$ cm^{-3} was measured by using electric probes, and an optimum arc efficiency of 0.46 A/kW was estimated with ion saturation current of the probes, arc power, and total beam area. An arcing problem, caused by the structural defect of decelerating grid supporter, in the third gap was solved by the blocking of backstream ion particles, originated from the plasma in the neutralizer duct, through the unnecessary spaces on the side of grid supporter. A maximum drain power of 1.5 MW (i.e. 70 kV/21 A) with hydrogen was measured for a pulse duration of 0.5 s. Optimum beam perveance was ranged from 0.75 to 0.85. An improved design of accelerator for the effective control of beam particle trajectory should provide higher beam perveance.

1. Introduction

A neutral beam injection (NBI) system, to be used as an auxiliary heating system for the Korea Superconducting Tokamak Advanced Research (KSTAR), was developed and being tested at the NBTS [1]. The design requirements of a LPIS for the NBI system were a 120 kV/65 A deuterium ion beam and a 300 seconds beam pulse length, as well as an initial test ion beam of 80 kV/48 A for 20 seconds with hydrogen. The beamline components in the NBI system have been developed for a neutral beam power of 8 MW, finally injected to heat the core plasmas of KSTAR with three LPISs in a beamline.

The LPIS consists of a magnetic bucket plasma generator, with multi-pole cusp fields, and a set of tetrode accelerators with circular apertures [2]. The transparency of ion source was 48.8 % with 568 apertures of 7.2 mm diameter. Discharge characteristics of the LPIS were investigated, prior to the beam extraction experiments, for a discharge duration of 1 s. The ion source had to be run at an emission-limited mode to achieve the most efficient discharge condition. Thus, the arc characteristics were controlled by the primary electron emission, that is basically the applied voltage to the cathode filaments. Beam extraction experiments have been tried for a short pulse length of 0.5 s with hydrogen. The optimum beam perveance for the LPIS has been investigated by observing the ratio of the gradient grid current to the total acceleration current, and the experimental perveance for up to 70 kV was ranged from 0.75 to 0.85 μper. This was smaller than the expected design value of 2.1 μperv (i.e. 80 kV/48 A). A modified accelerator column was designed and is being manufactured. Thus, the improved accelerator in the LPIS for the effective control of beam particle trajectory should provide higher beam perveances.

2. Experiments and Results

2.1 Arc Discharge in Plasma Generator

The LPIS consists of a magnetic bucket plasma generator with multi-pole cusp fields, based on the US Common Long Pulse Ion Source (CLPIS) [3], and a set of tetrode accelerator with circular apertures. Dimension of the plasma generator is a cross section of 64326 cm2 and a 32 cm depth. Discharges of the plasma generator were initiated with primary electrons emitted from the cathode, consisting of 32 tungsten filaments, each of which has a wire diameter of 1 mm and three hairpin types. Arc discharges of the plasma generator were controlled by the emission-limited mode, controlled by using the applied heating voltage of the cathode filaments. Arc plasmas with a maximum arc power of 110 kW were produced stably and efficiently by using a constant voltage (CV) mode operation of the arc power supply, under a given heating voltage of the filaments. Maximum outputs of the discharge power supplies (filament and arc power supplies) were 15 V (dc), 3200 A CW and 160 V, 1200 A CW, respectively. The discharge power supplies were isolated electrically from the ground potential through an high voltage (HV) isolation transformer and located on the high voltage deck. To monitor the plasma ion density from the ion saturation current, 8 electrostatic Langmuir probes (molybdenum-wire tip with a diameter of 1 mm and a length of 3 mm) of an un-cooled type were installed at fixed positions around the probe plated. To obtain a stable arc discharge of up to 110 kW, a filament voltage of 6.5~8.6 V was applied.

Discharge characteristics of the plasma source were studied without extracting the beams. A filament voltage of 8.6 V leads to an arc power of 110 kW (with the arc current of 1200 A, which was limit of the output current) and a maximum ion density of $9.13 10^{11}$ cm^{-3}. In general, the ion density of the LPIS increases linearly with an increase of the discharge arc power. Figure 1 shows the

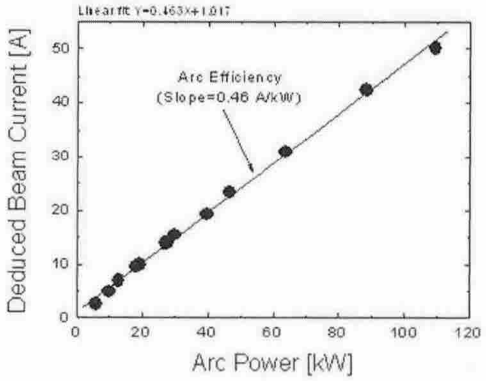

Figure 1. Deduced beam current and arc efficiency of the ion saturation current, as a function of the discharge arc power.

deduced beam current from the ion saturation current of the electrostatic probes, as a function of the discharge arc power for the beam extraction area (48.8 % of 11.6345.4 cm^2). The arc efficiency, defined as the extractible ion current per kW of the arc power, was obtained from the slope of data points. An optimum arc efficiency of 0.46 A/kW was estimated for the CV mode operation of arc discharge in the LPIS. This arc efficiency implies that an arc power of 110 kW is sufficient to support the extraction of 48 A (80 kV) of hydrogen ions, even though the actual extraction current is ultimately governed by the beam perveance range for the tetrode accelerator column.

2.2 Beam Extraction from LPIS

The beam extraction experiments have been carried out using an accelerating voltage of up to 70 kV by the Arc Beam Extraction Method (Arc BEM). In the Arc BEM, the accelerating voltage was applied prior to the arc plasma production, and the beams were extracted during the time of arc discharge. Another way of the beam extraction is the Accel BEM in which the arc plasma is produced prior to the accelerating voltage, and the beams are extracted during the time of applied accelerating voltage. Arc plasmas have been supplied at an arc power of 72 kW (i.e. 90 V/800 A), and the decelerating voltage of –2 kV was applied. The maximum output of the accelerating power supply as 120 kV, 70 A CW, and the decelerating power supply was rated for –5 kV, 25 A CW. The plasma grid and the gradient grid voltage were divided from the accelerating voltage by using a resistor bank of 25 kΩ. A typical ratio of the gradient grid voltage to the total was ranged from 0.76 to 0.8 after optimally adjusting the ion optics. The accelerating and decelerating voltages were applied repeatedly during each beam pulse by using a re-triggering mode operation (up to 100-repetitions) of HV switches, when the beam disruptions occurred. The rising time of the accelerating voltage was typically ≤25 μs. For stable beam extractions, the decelerating voltage was always applied prior to the accelerating voltage (delay time≤2 ms), in order to suppress effectively the back-streaming electrons produced at the time of an initial beam formation. For the short-pulse beam for 0.5 s, the filament were heated for ≤12 s, the arc discharges continued for ≤1 s, and the gas was introduced for ≤12 s. Figure 2 shows a perveance

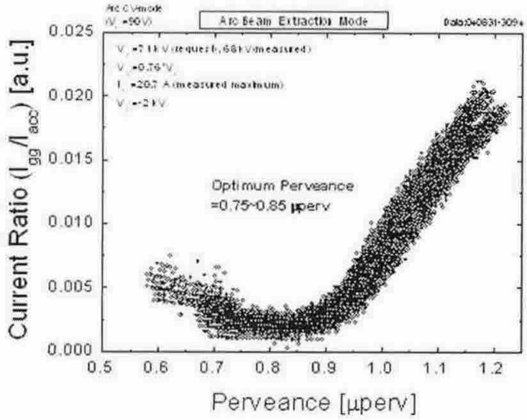

Figure 2. Current rtio of the gradient grid current (I_{gg}) to the total beam (I_{acc}) for the beam perveance scan.

scan at 68 kV (beam current of 11 A~22 A), where the ratio of the gradient grid current (I_{gg}) to the total beam current (I_{acc}) is plotted against the perveances (1 μperv≡10^{-6} A•$V^{-3/2}$). Optimum beam perveance was from 0.75 to 0.85 accepted the lowest region in the figure. Thus, a maximum beam power of 1.5 MW (i.e. 70 kV/21 A/1.13 μperv) was measured for the beam duration of 0.5 s.

3. Conclusion

A multi-megawatt long pulse ion source (LPIS) of neutral beam injector was developed for the KSTAR and tested at the NBTS. Stable and efficient arc discharges were produced in the LPIS. An optimum beam perveance was measured experimentally, and a maximum drain power of 1.5 MW beam was achieved from the LPIS.

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