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Discharge Properties of a Prototype Ion Source for KSTAR Neutral Beam System

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1. Introduction

A proto-type long pulse ion source (LPIS) has been designed, fabricated, and being tested on a test stand [1]. The goal is to produce a hydrogen/deuterium beam of 120 kV for heating KSTAR plasmas. The LPIS was designed to operate in an emission-limited mode (ELM) in which the arc discharge power was controlled directly by the filament heating temperature (filament voltage). It has been demonstrated that the discharge plasma density is dependent only upon the arc power. The discharge properties were investigated by a series of electric probes (Langmuir probes) and by the relation between discharge stability and cathode filament temperature.

2. Experimental Setup

The proto-type LPIS [2] consists of a magnetic bucket plasma generator and a four-grid actively-cooled copper accelerators with about 580 circular apertures. The power supply connection is shown in Fig. 1. Dimension of the plasma generator is a rectangular cross section of 64×26 cm^2 and a depth of 32 cm. Anode bucket has axial arrays of Sm-Co permanent magnets (about 4.65kG) providing 40 cusp lines. The electron dump, which is at the anode potential, has three arrays of magnets. The cathode consists of 32 tungsten filaments with hair-pin type (diameter = 1.5 mm).

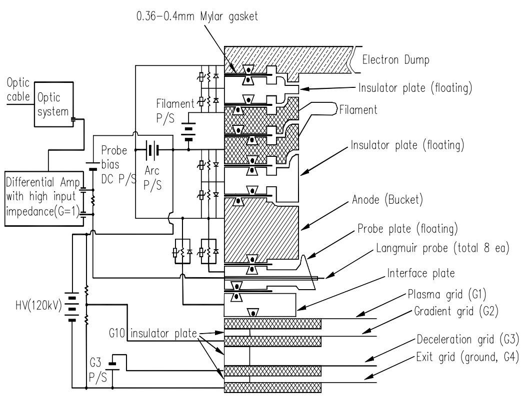

Figure 1. Power supply connections on the LPIS.

3. Analyses and Results

3.1 Discharge Potential Distribution of LPIS

The potential distribution of various electrodes of the LPIS was measured during arc discharge, using a digital multi-tester, and the result is shown in Figure 2. Electron dump and anode cylinder are tied together. Filament negative and positive plates serve as the cathode. As expected the floating electrodes take potentials between the cathode and the anode.

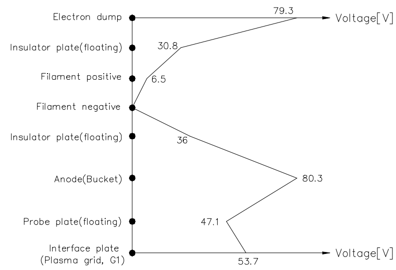

Figure 2. Potential distribution of the LPIS for 4-sec discharge with 80 kW arc power.

3.2 Discharge Mode Change in LPIS

Discharge mode-flip phenomenon between ELM and inefficient discharge mode [3] was investigated along with filament effect on initial plasma generation and plasma stability. LPIS turns out to be very sensitive to thermal electron emission from the filaments. We found that two-step operation is very much needed, in which "cold" filament is maintained before the initiation of discharge. This process is essential to escape the discharge mode change at the initiation as a result of too hot filament. This mode flip phenomenon is not yet well understood. Excessive electron population may hinder stable initiation of discharge. It could be due to that the plasma potential drops substantially below the anode potential.

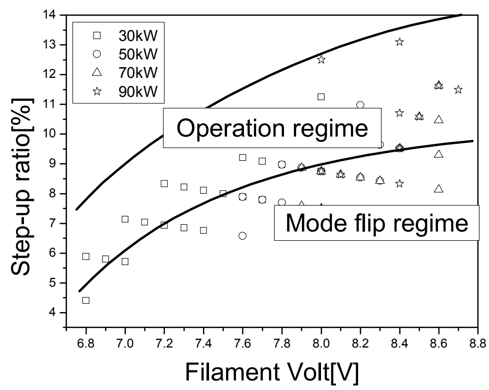

Figure 3 Filament voltage step-up ratio with post arc voltage.

Given an arc power setting there is a range of filament temperature (monitored by filament voltage) for which the arc is stable. For a given filament operating voltage, there is a minimum amount of filament voltage step down (making the filament colder) before the initiation of arc. Figure 3 shows the experimentally determined filament voltage step-up amount (percent of the operating voltage) for which arc starts stably without mode-flip.

3.3 Discharge with Deuterium and Hydrogen

Deuterium gas discharge was tried in connection with the mode-flip problem. The discharge initiation of deuterium gas was much easier than the hydrogen gas. And we could not force deuterium discharge into mode-flip. As mentioned earlier, the ion saturation current (i.e., plasma density) of LPIS is determined solely by the arc power. Fig. 4 shows such properties for hydrogen and deuterium discharges.

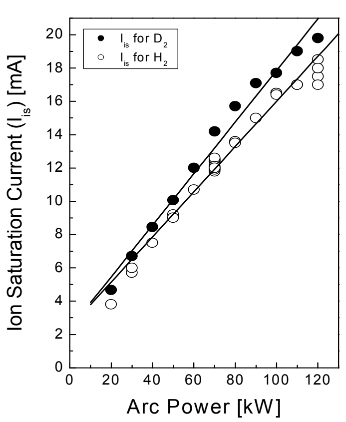

Figure 4 Ion saturation current of electrostatic probe versus arc power both for hydrogen and for deuterium discharges.

3.4 Study of Discharge Plasmas by Electrostatic Probe

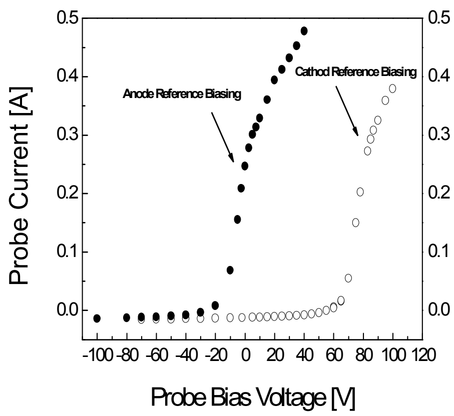

Figure 5. I-V characteristic curve of LPIS for the cases of cathode and anode reference biasing voltages.

Typical I-V curves of a Langmuir probe (cylindrical type with a diameter of 3 mm and a length of 1 mm) is shown in Fig. 5 for two cases of references, that is, to the cathode or the anode. The I-V characteristics are almost identical regardless of the reference. The arc voltage for the two cases was 80 V. Plasma potentials were determined as the point where the knee occurs and it is 82.3 V above the cathode potential and 2.7 V above the anode potential, respectively. The plasma potential is a few volt above the anode potential. The electron temperature was deduced as 8-10 eV and the ion density ~3.5E11 cm^{-3}.

Expected beam current was calculated with the total beam area (12×45 cm^2) and the transparency of accelerator (44 %) in LPIS. The relationship between the extracted beam current (I_{beam}) and the ion saturation current of electrostatic probe (I_{is}) is shown in Fig. 6.

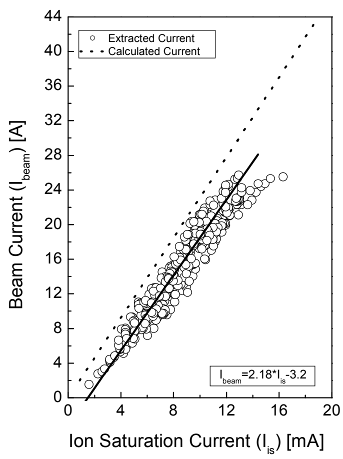

Figure 6. Actual extracted current versus ion saturation current. The calculated beam current is the dotted line

4. Conclusion

Discharge properties of the LPIS were investigated in an effort to improve the efficiency of arc discharge. The operational ranges and limits were investigated for the stable discharge operation of the filament voltage while extraction ion beams. Study of LPIS discharge in connection with arc efficiency (extracted ion current per kW of arc power) is still on-going. Restarting of beam after a high voltage breakdown is seriously hindered by the step operation of filament heating, which needs to be solved for long pulse operation

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