ANALYSIS OF BEAM QUALITY OPTIMIZATION OF BUCKET ION SOURCE

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Abstract

The bucket ion source is widely used as the high energy beam source on the high power neutral beam injector system. A hot cathode bucket ion source is studied. The main parameters which influence the performance of bucket ion source are arc voltage, filament voltage, gas inlet rate and extracted voltage. The proton ratio is the dominate parameter for the ion source. In the experiment, the characteristics of ion source are got by regulate the parameter setting. Based on this, the beam proton ratio, are analyzed and optimized. The proton ratio of extracted beam increased from 28 % to 40 %. It is very useful for the experimental operation and study about the bucket ion source.

INTRODUCTION

The high power neutral beam injection (NBI) is wildly used for the realization of controlled thermonuclear fusion sciences. The high current ion source is one of the most important parts on NBI, and it is characterized as high plasma density, large dimensions and high proton ratio. In order to promote the performance of ion source, the researchers did many study and experiments, one of them is the proton ratio.

The proton ratio is define the percentage of the number of atom ions in the over all species ions number. Consider the hydrogen as the experimental gas, it may generate ions of H1+, H2+, H3+, and the proton ratio[1] can be defined as

$$\eta = \frac{I_{H_1^+}}{I_{H_1^+} + I_{H_2^+} + I_{H_3^+}} \approx \frac{n_1}{n_1 + n_2/\sqrt{2} + n_3/\sqrt{3}} \quad (1)$$

Where, n1, n2, n3 is the ion density of H1+, H2+, H3+, respectively.

The ions are used to accelerate from the arc chamber to form the ion beam, but the energy of molecular ions only 1/2 and 1/3 compare with the atom ions, therefore, the number of atom ions in the plasma is expected as high as possible. That is means that, the proton ratio of ion source should be promoted.

The usual used ion source is hot cathode ion source, and also is the wide used, which can be seen in Figure 1. It contains plasma generator and beam extraction system. The plasma generator contains the filaments, and the gas inlet and arc chamber, which surrounded with permanent magnets to form cusp magnetic to confine the plasma.

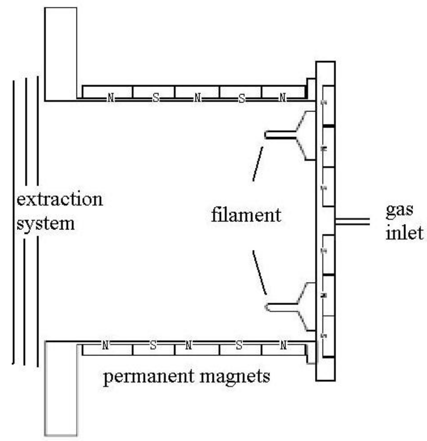

Figure 1: A sketch map of bucket ion source.

THE PHYSICAL MECHANISM OF PLASMA DISCHARGE

The ion source is a complicated device, including the plasma generate part and beam formation part. The particles in the plasma are used to form the ion beam, so, the ion species can decide the proton ration of extracted beam. And the plasma generation is only discussed. The principle of plasma generated in the hot cathode ion source can be described briefly as follows: The filament is supplied by a voltage and is then heated to emit thermo-electrons. When the arc voltage applied on the filament and arc chamber, the thermo-electrons are accelerated by the electric field. When the electrons energy large than the ionization potential of gas, the gas can be ionized and the plasma is generated. In case of hydrogen, it can generate atom ion H+ and molecular ions H2+, H3+. The formation of ions is a complicated thing, it contains many processes, and the collision cross-section of each process can decide the ion species which generated in the plasma. The electrons collide with the gas including one-collision and multi-collision. For the one-collision, mainly produce molecular ion H2+, the atom ion H+ almost produced in the second collision or more[2,3]. The collision processes are listed in Table 1. It can be seen that it including the molecules ionization, molecular ions dissociation, excitation and composition. The table also shows the threshold energy when the process take place, the collision cross-section and the optimize electron energy. Choose the big collision cross-section processes and give

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Table 1 The processes of arc discharge in the arc chamber[4]

NO	Processes	Threshold energy (eV)	σ_{max} ($10^{-16}cm^2$)	E_{max}(eV)
I	H_2 dissociation and excitation: $H_2 + e = H_2^* + e = H + H + e$	8.8	0.9	17
II	H_2 ionization: $H_2 + e = H_2^+ + 2e$	15.4	0.98	70
III	$H_2 + e = H^+ + H + 2e$	18	0.058	100
IV	H_2 dissociation and ionization: $H_2 + e = H^+ + H^+ + 3e$	46	0.005	120
V	H_2^+ dissociation and excitation : $H_2^+ + e = H^+ + H + e$	12.4	4.3	≈24
VI	H_2^+ dissociation and composition: $H_2^+ + e = H_2^* = H + H$	Heat energy	(100)	≈0
VII	H_2^+ dissociation and ionization : $H_2^+ + e = H^+ + H^+ + 2e$	17	0.18	105
VIII	H ionization: $H + e = H^+ + 2e$	13.6	0.7	64
IX	$H + e = H^*(2p) + e$	10.2	0.74	50
	$H + e = H^*(2s) + e$	10.15	0.14	12
X	$H^*(2p) + e = H^+ + 2e$	3.3	17	9
	$H^*(2s) + e = H^+ + 2e$	3.3	9.4	13
XI	H_2 excitation: $H_2 + e = H_2^* + e$	11.5	0.16	60
XII	H_3^+ formation: $H_2^+ + H_2 = H_3^+ + H$	Heat energy	(100)	≈0
XIII	H_2^+ charge exchange: $H_2^+(q) + H_2(s) = H_2(q) + H_2^+(s)$		7	3600
XIV	H_3^+ dissociation and composition : $H_3^+ + e = H + H + H(=H_2 + H)$	Heat energy	(100)	≈0
XV	H_3^+ dissociation and excitation : $H_3^+ + e = H_2^+ + 2H + e$	15	3.5	17
XVI	H_3^+ dissociation and excitation : $H_3^+ + e = H_2^+ + H + e$	12.4	4.3	≈24

the cross-section as a function of electrons, which show in Figure 2.

From Figure 2, we can seen that, when the electron energy achieve about 80eV, the collision cross-section to produce H+ and H2+ can reaches the maximum value. And when the electron energy increased, the collision cross-section decreased slowly. According the Schottky effect and double sheath stable theory[1], increase the arc voltage properly can increase the emission of thermo-electrons and got high arc current and plasma density.

According the literatures[5,6], the electrons with small energy can dissociation molecular ion H3+ to produce atom ion H+, it is an effective way to increase the proton ratio, especially in the extraction area. Besides, high arc current can easily to get high proton ratio[7].

EXPERIMENT RESULTS

In the experiment, a hot cathode bucket ion source is used and can generate hydrogen plasma. The ion source typical parameters setting are as follows:

- Arc voltage: 100V-200V
- Filament voltage:5V-8V
- Arc current: more than 100A
- Arc chamber pressure: ～4 mTorr
- Extraction voltage: 35kV-45kV
- Extraction current: more than 4A

The ion source operated with high temperature filament, but control the filament works in the emission limited regime [8]. The arc voltage is expected to high and gas inlet ratio should be regulated in a small range.

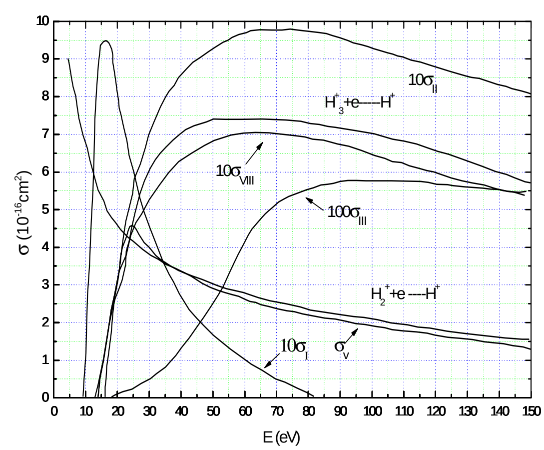

Figure 2: The collision cross-sections of main processes as a function of electron energy

The spectrometer is used to study the effect of operating parameters setting on proton ratio. Through regulate the parameters setting according to the theory and experimental experiences [9], the spectrum of the extracted beam emitted Hα light is measured and the typical spectrum is shown in Figure 3. The beam fractions of H+ : H2+ : H3+ : H2O+ is in the ratio of 40% : 34.7% : 9% : 16.3%.

The experiment studies the influence of beam current on the beam proton ratio. The arc current (beam extraction current) increased by regulate the ion source parameters, the beam ion species are measured and the results shown in Figure 4. The proton ratio increased with the extraction current, which is in accord with the theory and experimental results.

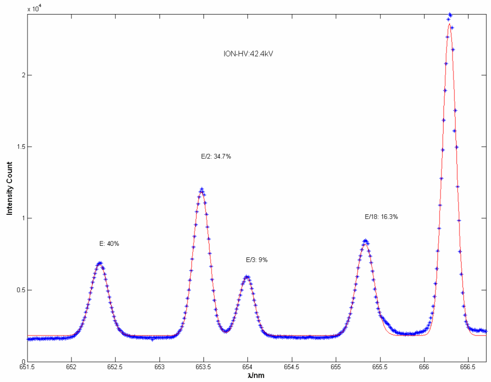

Figure 3: Spectrum of the H_α lines of ion beam

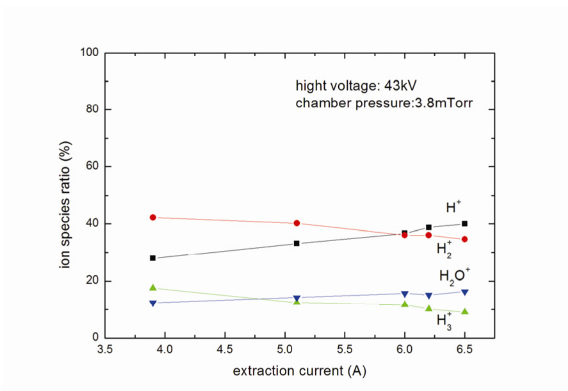

Figure 4: Proton ratio as a function of extraction current

SUMMERY

The proton ratio is an important parameter for high current ion source, which employed for NBI. It is mainly dominated by the collision cross-section between the electrons with different ion species in the arc chamber. Through analyze these collisions processes, gives the principle of arc discharge regulation. Even many researches were done to pursue high proton ratio, more studies need to do in the future.

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