Arc discharge characters of bucket ion sources with different magnetic configurations for neutral beam heating on HL-2A Tokamak

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1. Introduction

Magnetic multi-pole line-cusp configurations are wildly used in Bucket ion sources of Neutral Beam Injectors (NBI) to well confine primary electrons and get higher arc discharge plasma density. The ion source of NBI system on HL-2A Tokamak is a circular bucket ion source with magnetic multi-pole line-cusps[1].To investigate the influence of magnetic configurations on arc discharge characters, several circular bucket ion sources with different magnetic configurations are manufactured.

2. Arc discharge chambers with different magnetic configurations

The discharge chamber of the source is a water-cooled, stainless steel cylinder with 26cm in diameter. The hair-pin-shaped tungsten filaments, which are 1.5mm in diameter and 15cm in length, are attached to the filament holders at the top of the chamber. The arc chamber wall serves as anode, which is surrounded by several lines or turns of Co-Sm permanent magnets to form the cusp magnetic field, with the magnetic strength of about 2000G at the inside surface of the wall. To study the influence of the magnetic configurations on the arc discharge characters, we firstly decreased the lists of magnets on the side wall of the arc chamber, then decreased the depth of the arc chamber, also manufactured a chamber with several turns of magnets on the side wall.

1) 36 lists of magnet, 24cm long

   There are 36 lists of permanent magnets with 21.8cm long, 6cm wide and 10cm thick for each list of magnet. The magnetizing direction of the permanent magnet on the side wall of the chamber is along diameter of the chamber. The discharge chamber is 24.6cm deep and has 9 hairpin tungsten filaments arranged inside. There are also permanent magnet arrange in the back plate of the chamber. This kind of arc chamber is shown in figure 1.

2) 20 lists of magnet, 24cm long

   We adjusted the arrangement of magnets on the back plate, the number of filaments is adjusted to 10.

3) 20 lists of magnet, 21cm long

The depth of the chamber changes to 21cm. There are 20 lists of magnets with 18.6cm long, 6cm wide and 10 cm thick for each list of magnet. 10 filaments are arranged inside, as is shown in figure 2.

4) 7 turns of magnet, 21cm long

There are 7 turns of magnets on the side wall which forms circular cusp magnetic field. The chamber is 21cm long and has 10 filaments inside, as is shown in figure 3.

Figure 1 arc discharge chamber with 36 lists of magnets, 24 cm long

Figure 2 arc discharge chamber with 20 lists of magnets, 21cm long

Figure 3 arc discharge chamber with 7 turns of magnets, 21cm long

3. Estimation of the characteristic parameters of arc chambers

Plasma confinement length is a very important parameter, which is defined as the ratio of plasma volume to the ion loss area[2,3],

$$l_p = V_p / S_L \,, \quad (1)$$

Where V_p is plasma volume and S_L is the ion loss area.

$$V_p = (l-2\delta)(W-2\delta)(d-\delta) \,, \quad (2)$$

Where l, W, d are sizes of the chamber in 3 directions. δ is the length of the dead space, and is estimated as 4.6cm here[4].

$$S_L = 1/2(l-2\delta)(W-2\delta) + S_F + S_A \,, \quad (3)$$

Where on the right side the first term is ion loss area on the plasma grid, the second term is ion loss area on filaments and their supporters, the third term is the ion loss area near the cusp lines.

$$S_\mathrm{A} = 2\mathrm{L}(M_i V_i / eB) \,, \quad (4)$$

Where B is the magnetic field strength on the anode surface, L is the total length of the cusp lines, $\mathrm{M_i}$ is the ion mass, $\mathrm{V_i}$ is the escaping speed of ions to the anode surface, normally set as ion acoustic velocity[3,5] , $\mathrm{V_i} = C_S = \left(\frac{kT_e}{M_i}\right)^{1/2}$.

The discharge gas is deuterium. Suggesting the electron temperature of the produced plasma is about 3eV, the magnetic field strength on the surface of the chamber along the cusp lines is 2000G, the ratio of D_1^+ D_2^+ D_3^+ is 0.7,0.25,0.05. The ion loss area near the cusp lines is

$$S_A = 2L(M_iV_i/eB) = 2L(M_ikT_e)^{1/2}/eB \approx 2L*0.13*(0.7+0.25*\sqrt{2}+0.05*\sqrt{3}) \approx 2L*0.13*1.025(cm^2) . \quad (5)$$

Assumes the surface area of each filament supporter is 2 cm^2 , then the character parameters of the arc chambers are:

Arc chambers	V_p (cm³)	S_F (cm²)	S_A (cm²)	S_L (cm²)	l_p (cm)
36 lists of magnets, 24 cm long	4433	82	196	389	11. 4
20 lists of magnets, 24 cm long	4433	91	171	373	11. 9
20 lists of magnets, 21 cm long	3635	91	155	357	10. 2
7 turns of magnets, 21 cm long	3635	91	208	410	8. 9

4. Comparison of the arc discharge volt-ampere characters

By scanning the arc discharge parameters and arc currents, the arc voltage -arc current characters at different discharge parameters are obtained, figure 4 shows the result with the pressure at 0.5~0.6Pa. It shows that the arc voltage all increases will arc current. For the same arc current, the arc voltage is obviously larger in the shorter ion sources (ion2_20_short and ion2_7_short) than that in the other arc chambers. The results with pressures at 0.3~0.4Pa, 0.4~0.5Pa, 0.7~0.8Pa all shows the same trend and difference between the shorter arc chambers (20 lists of magnets, 21 cm long &7 turns of magnets, 21 cm long) and longer arc chambers(36 lists of magnets, 24 cm long&20 lists of magnets, 24 cm long).

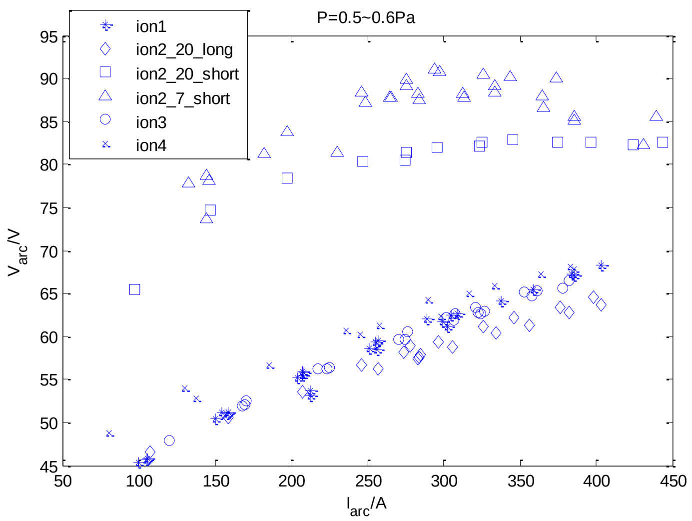

Figure 4 arc voltage-arc current distributions in different arc chambers. Ion1, ion3 ion4 are arc chambers of 36 lists of magnets and 24cm long; ion2_20_long is arc chamber of 20 lists of magnets, 24cm long; ion2_20_short is arc chamber with 20 lists of magnets, 21cm long; ion2_7_short is arc chamber with 7 turns of magnets, 21cm long.

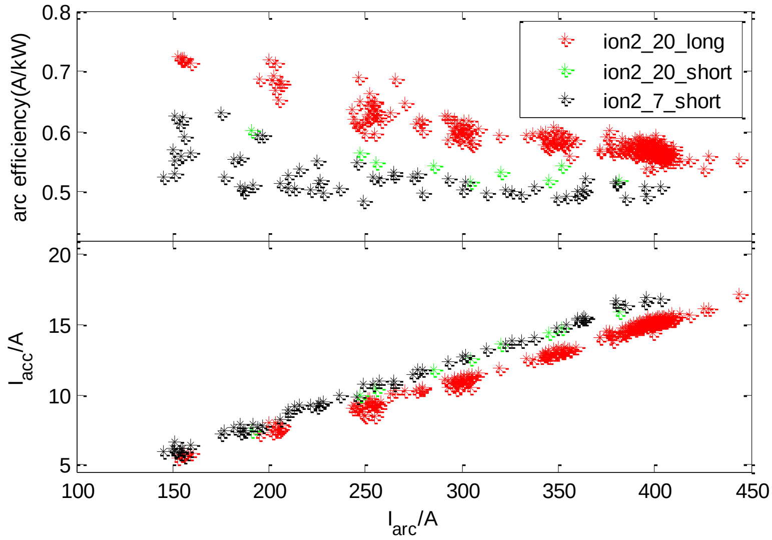

Figure 5 the extraction current and arc efficiency vs. arc current.

According to the extraction experiment result, it shows that the extraction currents all increase almost linearly with the arc current. Though the extraction current is slightly higher in the ion sources with shorter discharge chambers, but the arc efficiency is obviously lower in the ion sources with shorter discharge chambers.

5. Summary

To study the influence of magnetic cusp field configurations of ion source on the arc discharge, several kinds of ion source arc discharge chambers were manufactured. The parameters are estimated for the arc chambers. It turns out that: the confinement length of the (1)(2) arc chamber are longer, separately is 11.4cm and 11.9cm; while that of the (3)(4) arc chamber are shorter, separately is 10.2cm and 8.9cm. Comparison work of the volt ampere characteristics between ion sources is done. It turns out that, with the same discharge conditions, the arc voltage in the shorter arc chambers are higher than that in the longer arc chambers, about 10V, and the arc efficiency in the ion sources with shorter arc chambers is lower than that in ion sources with longer arc chambers.

Reference

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