2.7 Optimization of experimental discharge parameters to increase the arc efficiency of the bucket ion source\(^1\)

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Arc efficiency is a critical criterion to assess the performance of the ion source. High arc efficiency is necessary for a high power ion source, because it can decrease the load of the arc power supply. The arc efficiency is defined as:

\[
\eta_{\text{arc}} = \frac{J}{I_{\text{arc}}} \times \frac{I_{\text{arc}}}{P_{\text{arc}}}
\]

Where, \(\eta_{\text{arc}}\) is arc efficiency, \(I_{\text{arc}}\) is extraction ion current, \(V_{\text{arc}}\) is arc voltage, \(P_{\text{arc}}\) is arc current, \(P_{\text{arc}}\) is the power of arc supply, and \(J_{\text{arc}}\) is the saturated ion current density.

For the measurement of the discharge parameters, sensors are utilized to measure \(I_{\text{arc}}\) and \(V_{\text{arc}}\), and \(I_{\text{arc}}\) is measured by the voltage divider. The gas pressure pin arc chamber is measured by gauge. The saturated ion current density is measured by an electrostatic probe biased at \(-120\) V referred the anode area, so the probe only collects the ions.

In experiment, the parameters \((P, I, V, \text{and the bias resistance } R_{\text{bias}})\), which may affect the arc efficiency, are scanned separately, and the other parameters are kept unchanged.

Keeping \(I = 1050\) A, \(V = 84\) V, \(R_{\text{bias}} = 20\) Ω, the relationship between the gas pressure and the arc efficiency can be got by scanning the gas pressure, as shown in Fig. 1.

From Fig. 1, it can be observed that when the gas pressure is below 0.4 Pa, the arc efficiency increases very fast with the increase of the gas pressure. But when it is above 0.4 Pa, the arc efficiency increases slowly or even stays unchanged with the increase of pressure. So the gas pressure is better to be set at 0.4 Pa, resulted in that not only the arc efficiency is high, but also discharging breakdown between the grids is avoided. When the gas pressure is confined near the limit of 0.4 Pa, the vacuum operation is allowable.

It is considered that when the gas pressure is low, the primary electrons emitted from the filaments moves to the plasma grid directly without collision with the gas in discharge chamber. While the gas pressure increase, more and more primary electrons collides with the gas atoms instead of the plasma grid.

For the stability of arc discharge, the plasma grid and the anode area are connected by bias resistances with different value and are even short. Keeping \(I = 1050\) A, \(V = 85\) V, and changing the bias resistance into \(0\) \(\Omega\), \(2\) \(\Omega\), \(10\) \(\Omega\), \(20\) \(\Omega\) and \(150\) \(\Omega\), by scanning the gas pressure, it is found that the larger the bias resistance, the higher the arc efficiency, but when the resistance is above \(20\) \(\Omega\), the difference is not so obviously under high pressure condition. When the pressure is below 0.4 Pa, the larger the bias resistance, the faster the arc efficiency increases with pressure, as shown in Fig. 1.

It is supposed that when the anode and plasma grid are in short, the anode voltage is equal to that of plasma grid, and the effective anode area is the sum of the anode area and the area of plasma grid, but when in floating voltage the effective anode area is only the anode area. So in the former situation the anode area is bigger, and more electrons losses to the big anode area, so the arc efficiency is lower. Increasing the bias resistance can decrease the effective anode area, so the electrons lost to the effective anode area also decreases, and the electrons confinement becomes better. So at the same arc current, larger bias resistance means higher saturated ion current density.

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Fig. 1. Relationship between the gas pressure and arc efficiency.