Design of gas flow control of RF negative hydrogen ion source based on ASIPP NBI test facility

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Abstract

The gas pressure during plasma discharge affects the density and temperature of its electrons, which is essential to realize the steady-state operation of the radio frequency negative hydrogen ion source used in the nuclear fusion auxiliary heating experimental facility. In order to maintain the density and uniformity of the plasma and improve the operating efficiency of the ion source. It is necessary to keep the gas pressure during plasma excitation of the ion source and the gas pressure during beam extraction within a certain range. By simulating the dynamic changes of vacuum in the ion source with different gas flow rates, gas intake times and pumping speeds, hardware circuits are designed to control solenoid valves and mass flow controllers (MFC) to achieve the precise control of gas flow. The experimental results in the RF test facility of ASIPP NBI show that the precisely controlled gas flow strategy designed has better repeatability and more stable density and uniformity of the plasma .At the same time, gas flow is also an important reference for the calculation of the real-time pumping speed performance of cryopumps and the analysis of the reasons for the failure of the beam extraction experiment.

Motivation

- During the operation of the radio frequency ion source, the pressure of the plasma discharge directly affects the density and temperature of electrons.
- In addition, it must be considered that the gas pressure used to excite the plasma is relatively high, and it should be avoided that the gas inlet load is too large, which will cause the molecular pump to work overload, and even cause vacuum damage.
- It is necessary to accurately control the gas flow of the ion source to achieve the purpose of high-power long-pulse steady-state operation.

Method

Mean free path: $\lambda_e = \frac{kT}{\sqrt{2}\pi d^2 p}$

Average power of electrons:

$$P = \frac{1}{2} \cdot \frac{n_e e^2}{mv} \cdot E_0{}^2 \cdot \frac{v^2}{v^2 + w^2}$$

Typical Gas use efficiency:

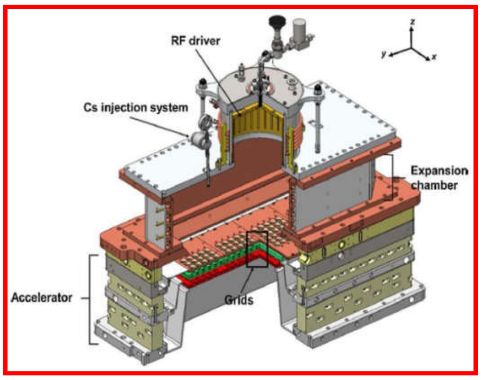
$$\xi = \frac{N_{ion}}{N_{total}} = \frac{I_{beam}}{2.66 \times 10^{17} eQ} (\eta_1 \frac{\mu_1}{\mu_2} + \eta_2 + \eta_3 \frac{\mu_3}{\mu_2})$$

Required gas flow (Q vs I_{beam}):

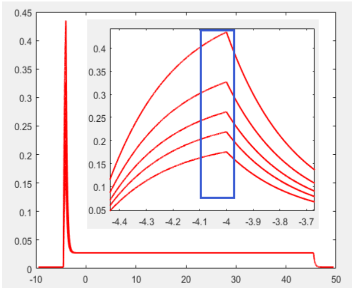
$$Q \approx 30 I_{beam} \quad when \quad \xi = 50\%$$

Gas pressure in ion source chamber:

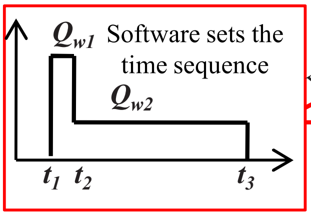
$$p = \begin{cases} \frac{Q_l}{S} & t_0 \le t < t_1 \\ -\frac{Q_{w1}}{S} e^{-\frac{S}{V}(t-t_1)} + \frac{Q_{w1}+Q_l}{S} & t_1 \le t < t_2 \\ (\frac{Q_{w1}-Q_{w2}}{S} - \frac{Q_{w1}}{S} e^{-\frac{S}{V}t_0}) e^{-\frac{S}{V}t} + \frac{Q_{w2}+Q_l}{S} & t_2 \le t < t_3 \\ \frac{Q_l}{S} + \frac{Q_{w2}}{S} e^{-\frac{S}{V}(t-t_3)} & t > t_3 \end{cases}$$



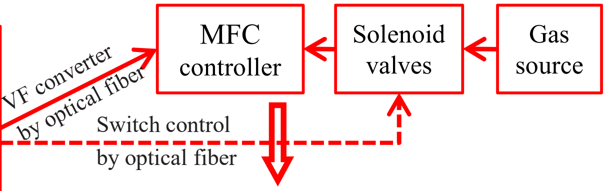
3-D diagram of the RF driven ion source



Simulation of pressure variations at different inlet gas flow



Software sets the time sequence



VF converter by optical fiber

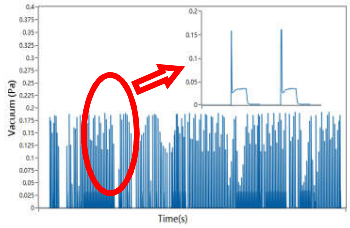
MFC controller

Solenoid valves

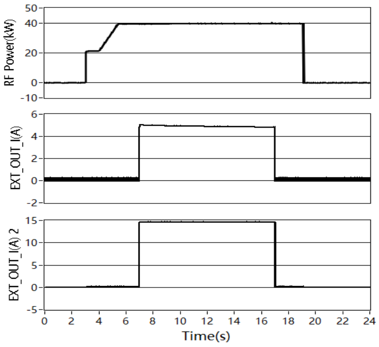
Gas source

Switch control by optical fiber

ASIPP NBI test facility of RF ion source



Repeatable gas pressure waveforms with the same parameters



Waveforms of RF power, extraction voltage, and extraction current under repeatable air pressure