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Full Length Article

Proton beam simulation of duoplasmatron ion source for diagnostic neutral beam of Alborz tokamak

M. Kazemi, R. Amrollahi*

Amirkabir University of Tehran, 424 Hafez Ave, Tehran, 15875-4413, Iran

A R T I C L E I N F O

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A B S T R A C T

Plasma (ion) sources such as duoplasmatron are widely used in several important technological applications. In this paper, the extraction of the proton beam from the duoplasmatron ion source has been simulated with Computer Simulation Technology (CST) software through its particle tracking module as a part of the verification process determining the operational parameters of a new beamline. The obtained results indicated that minimum divergence was achieved when the DP perveance is equal to 0.47 of the perveance of planar diode, which is close to the theoretical value of the optimum divergence. The plasma boundary location in front of the ground electrode was considered as the simulation parameter. This parameter depends on the plasma density and magnetic field lines configuration. In the present study, simulated beam divergence has been compared with experimental data obtained from image processing of side-view of beam with Mathlab code. The applied parameters in all simulations are determined based on the required features of DP ion source in Amirkabir University of Technology (ADP) which is currently being constructed.

1. Introduction

Duoplasmatron (DP) was first reported by Von. Ardenne in 1956 [1], is widely used in many domains of experimental physics including particle accelerator [2], diagnostic and neutral beam heating (DNB) in tokamak, material sputtering [3], etc. DP has the advantages of having a wide range of ion beam intensity (10^{-3}–10 A) with high brightness, high gas efficiency (50%–90%), high proton content, the capability to produce a multi-charged ion or a negative ion [4], exceptional phase-space characteristics and small energy spread [5]. Microampere DP has been commercialized in many applications. DP with current in the order of mA is used in accelerator devices. For instance, the existing DP in Korean accelerator produces up to 35 mA of H^+ current with an emittance < 0.02 π-cm-mrad (rms, norm) for injection into the RFQ [6]. In addition, the DP ion source for plasma diagnostics is used in Alcator C-mod tokamak with the capability of providing 8 A, 54 keV proton beam in maximum 3 s pulses [7].

The operational details of DP are discussed in many reports. Generally speaking, the arc plasma is formed between the anode and the filament as the hot cathode in low voltages (100–500 V) resulted from the electron emission of the hot cathode acting as a trigger. The soft iron intermediate electron (IE) geometrically and magnetically constricts the emitted electrons. A low plasma density, up to 10^{16}–10^{18} per m^3 is formed between filament and IE. The anode is a plane with an aperture about 0.3–2 mm in diameter. The hydrogen pressure in both sides of the anode is adjusted with a turbo vacuum pump and a gas flow rate inlet. The sufficient pressure in the arc chamber is about $20–100 \times 10^{-3}$ Torr and the beam side chamber pressure is about 5×10^{-5} Torr. Plasma diffuses to the low pressure side (beam chamber) from the orifice till the fluid pressure of plasma equals to the electric field pressure. Many parameters affect the plasma expansion into the beam chamber such as arc current, arc chamber pressure, plasma density, magnetic field profile on DP axis and beam chamber pressure.

In most applications of ion source, the extraction system should be perfectly design to achieve a ion beam with minimum divergence. In the present paper, the beam current and divergence of DP, as the most effective parameters determining the efficiency of ion source, has been studied. For this purpose, several simulations are performed by the particle tracking module of Computer Simulation Technology (CST) software. The location of the plasma boundary in front of the ground electrode was changed and its impact on the beam convergence was investigated. The considered parameters in all simulations are determined according to the DP ion source in Amirkabir University of Technology (ADP).

The DP power supply has also been simulated for generating a proton beam with a current of 1–30 mA and 200 mA in continuous and pulse (20 ms) modes, respectively. The low current continuous mode

* Corresponding author.
E-mail addresses: moslemkazemi@aut.ac.ir (M. Kazemi), amrollahi@aut.ac.ir (R. Amrollahi).

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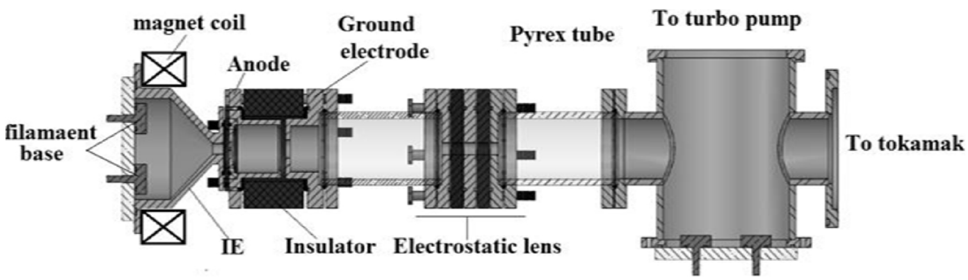

Fig. 1. Schematic of constructed DP and extraction system mechanical design.

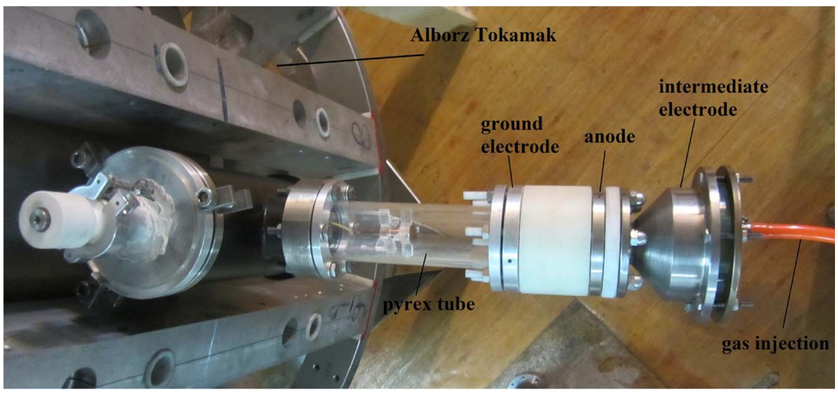

Fig. 2. Assembled DNB on Alborz tokamak with Pyrex tube for taking picture from beam and without magnet and relevant power supply.

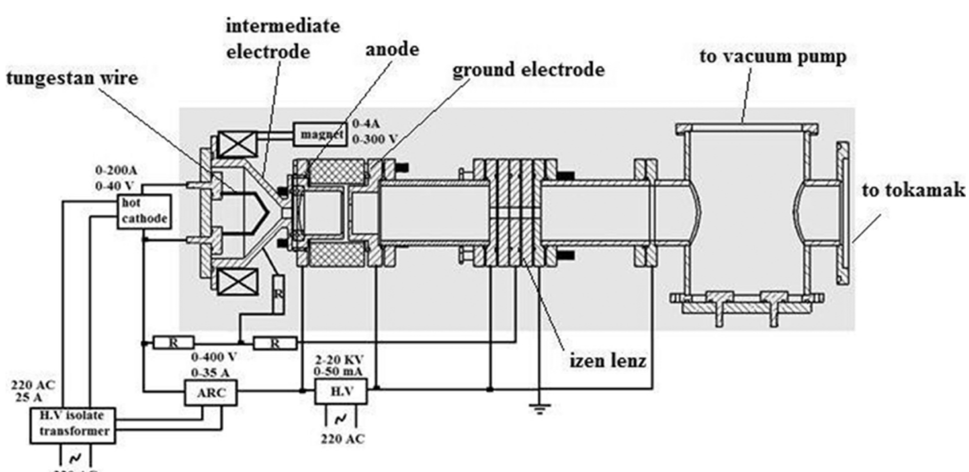

Fig. 3. Electrical block diagram of DP ion source and extraction system.

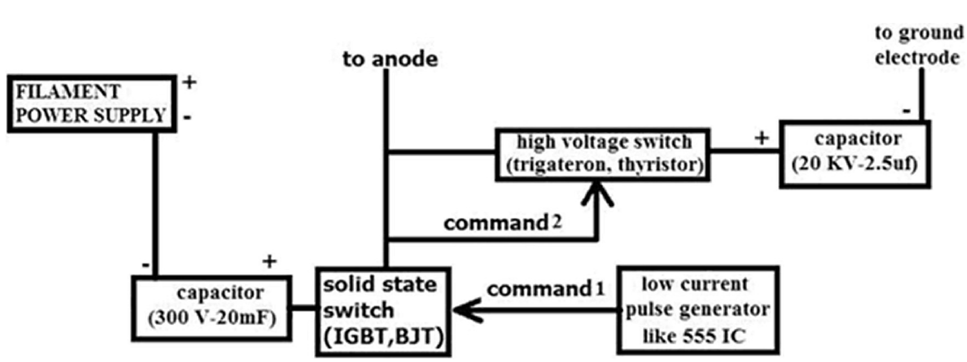

Fig. 4. Block diagram of arc and high voltage DP ion source and extraction system.

can be used in typical applications and the high current pulse operation mode is used as the neutral beam probe in Amirkbir Alborz Tokamak (AT). Continuous power supplies are ordinary, while in the pulse mode operation, the exact time sequence should be specified.

The detailed experimental set up is presented in Section 2. The electrical simulation of DP ion source in pulse mode and its synchronization with AT power supply are presented in Section 3.1. The DP beam current and divergence are studied in Section 3.2 and the optimum operational condition of DP has been obtained.