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Optimization of the gas flow in the neutralization region of EAST neutral beam injector

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ABSTRACT

According to the problems encountered in the experiments of the EAST neutral beam test stand, the design of neutralizer of EAST neutral beam injector is suggested to modify to optimize the gas flow in the neutralization region. The modifications contain narrowing the slits between the neutralizer and the mounting flange hole, and rotating the gas injection angle from 90° to 60° in the neutralizer. In this paper, an adjusted Direct Simulation Monte Carlo (DSMC) code was used to estimate the modification. The results show that a little change of the slits width causes a large variation of gas target thickness, and the rotation of the gas injection angle can effectively reduce the gas density near the accelerator but with a little of decrease of target thickness.

1. Introduction

To achieve the scientific mission of the experimental advanced superconducting tokamak (EAST) project, a neutral beam injection (NBI) system is being developed and tested as a high power auxiliary heating and non-inductive current driver system [1,2]. Before the EAST–NBI system operates in 2014, a neutral beam test stand (NBTS) system has been built to estimate the performances of the mega-watt ion source and the internal components of beamline [3–6]. The NBTS has a similar design with the EAST–NBI. So far, a high power ion beam of 3 MW with 80 keV beam energy in 0.5 s beam duration and a long pulse ion beam of 100 s with 50 keV beam energy were achieved on the NBTS [7,8].

A CAD drawing of the EAST neutral beam injector is shown in Fig. 1. In neutralization region, parts of the energetic ions from the ion source turn into neutral particles by charge exchange collision with gas target. And then, these energetic neutral particles move through the remainder of beamline, cross the magnetic field and reach the plasma region of EAST. Thus, neutralization efficiency of ion beam has an enormous influence on the neutral beam power and heating effect. And the neutralization efficiency depends on the gas target thickness [9], also known as gas linear density in the neutralization region $nL(=\int n \cdot dl)$, n is the neutral gas density and L is the length coordinate. Since Paméla proposed gas heating effects [10], related investigations in the gas neutralizer have attracted more and more attentions. These investigations focused on different physical characters, such as gas target depletion by gas heating [11–14], gas flow modeling [15–17] and plasma generation through beam-gas interaction [18–20].

To optimize the gas flow in the neutralization region, the design of neutralizer of EAST neutral beam injector is suggested to modify. The modifications include narrowing the slits between the neutralizer and the mounting flange hole, and also rotating the gas injection angle from 90° to 60° in the neutralizer. The effect of such modification was studied by an adjusted direct simulation Monte Carlo (DSMC) code, which has been successfully applied to the neutralization region of ITER and EAST neutral beam injector [21–23]. In this paper, the modification and the R&D results for the EAST neutral beam injector were reported.

2. Proposed modification in the neutralization region

The EAST neutral beam injector is based on the common long pulse source (CLPS) [24,25], which is composed of a plasma generator (arc chamber) and a four-electrode (tetrode) accelerator. The neutralization efficiency of such positive ion source increases with gas target thickness and tends to saturation gradually [26]. Upon that, the target thickness required to achieve 95% of the maximum neutralization efficiency is defined as the optimum target thickness, which ensures a sufficient neutralization efficiency with a small gas injection. And the optimum target thickness varies with different beam species and beam energy due to the collision cross

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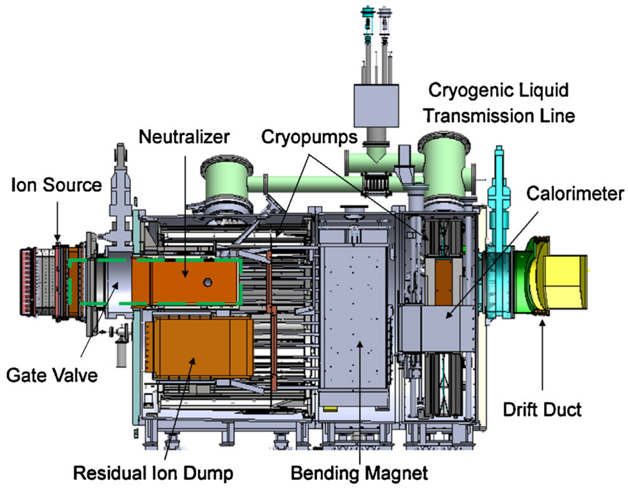

Fig. 1. CAD drawing of the EAST neutral beam injector.

section [27]. Once the ions are extracted and accelerated out of the electrode grids in the accelerator, they start the neutralization process. Hence, the neutralization region of EAST injector is from the last electrode grid to the end of neutralizer. It includes part of the accelerator, the cavity of the gate valve and the whole neutralizer, as enclosed by the green dashed frame in Fig. 1. The formation of target thickness is defined by the gas sources and geometry of the neutralization region. Gas sources contain the residual gas from ion source and supplement gas from neutralizer.

During the operation, it is expected to form the required target thickness with the lowest gas inlet quantity in the neutralization region. Because the abundant gas will effuse out of the region, imposing the overmuch gas load to vacuum system and the re-ionization losses of neutral beam [28]. Note that, for the easy installation, the beam hole on the mounting flange is bigger than the external dimension of the neutralizer. Thus the slits (>5 cm on the short side and >2 cm on the long side) are formed (shown in Fig. 2), which directly connect to the vacuum condition of beamline. As another exit of the neutralization region, the slits will reduce the gas density. Therefore, the width of slits should be limited to 1 cm in the future EAST neutral beam injector.

The gas inflow from the neutralizer will also diffuse through the accelerator into the arc chamber. Such excess gas may increase the number of energetic particles deposited on the accelerator grids and even disturb arc discharge for plasma generation [29]. And it was also regarded as the reason for the increasing breakdown of ion source, when the supplement gas puffed into the neutralizer during the experiments of NBTS. Because the size of each component is hardly changed, altering the gas injection angle into the neutralizer is considered as a simple solution. Altering the injection angle may reduce the gas flow to the ion source; however, the gas target thickness should not decrease too much.

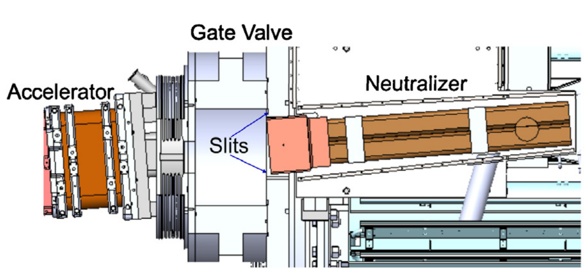

Fig. 2. Top view of the neutralization region of EAST neutral beam injector.

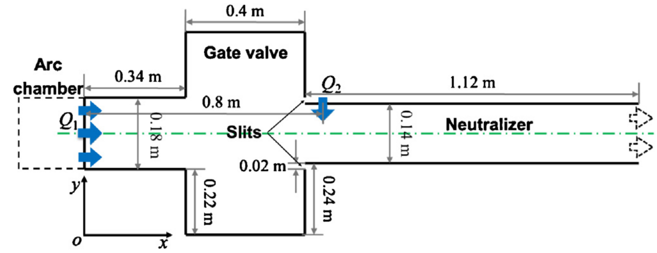

Fig. 3. The 2D model of the neutralization region of EAST neutral beam injector. Q_1 and Q_2 represent gas inlet quantity from arc chamber and neutralizer, respectively. The external space is assumed in a vacuum condition.

3. Results and discussion

The gas flow in the neutralization region was simulated to estimate the effect of the proposed modifications. The detailed descriptions of the adjusted DSMC code were published in Ref. [22,23]. The two dimensional (2D) physical model of the neutralization region of EAST injector was described in Ref. [23] and its dimension is displayed in Fig. 3. The length for calculating the target thickness nL here is 1.86 m (=0.34 + 0.40 + 1.12 m).

3.1. *Effect of narrowing the slits*

In the simulation, the deuterium gas is injected from the arc chamber and neutralizer respectively in the absence of beam, and the hybrid inlet gas pattern attracts more attention in the presence of beam. The gas flow rate of either gas source is fixed to 15 Torr l/s for comparison. It is easy to understand that the slits work as a pumping exit, which greatly reduces the formation of gas target in the neutralization region. The target thickness and the ratio of outflow through slits as a function of slits width is illustrated in Fig. 4. In both case, the reductions of target thickness are enormous when raising slits width per centimeter. When the slits width is 1 cm on the short side, the value of target thickness is nearly twice as that the slits width is 5 cm. Moreover, because the gas sources are closer to the slits than the exit of neutralizer, more gas tends to effuse through the slits. Hence, limiting the slit width to 1 cm can significantly improve the gas utilization.

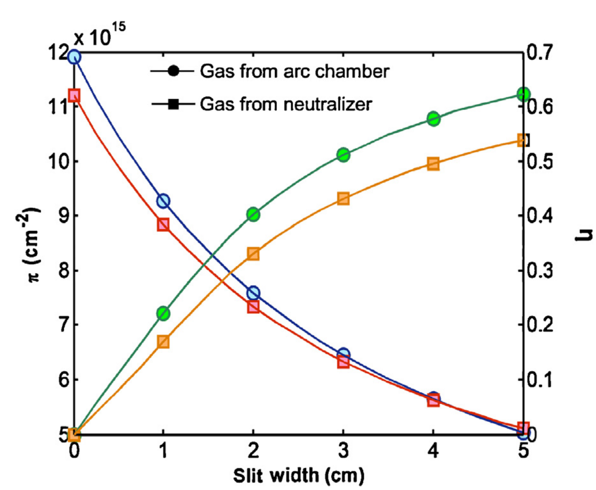

Fig. 4. The target thickness nL (solid lines) and the ratio of outflow through slit η (dash lines) as a function of slit width. The circles and squares represent gas from arc chamber and neutralizer, respectively.