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Analysis of the influence of the structure of radiation shield on its transmission probability for a cryo-condensation pump

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HIGHLIGHTS

- MC method is applied to study the present cryo-condensation pump of EAST-NBI.
- The influence of the pump structure on the transmission probability is studied.
- The boundary shape of the space above the cryo-condensation panel has little influence.
- The height of that space and the width of the cryo-condensation panel have main influence.
- The uniformity of the molecules is the direct factor to influence the transmission probability.

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ABSTRACT

The cryo-condensation pump used in EAST-NBI is composed of cryo-condensation panels cooled by liquid helium and radiation shields cooled by liquid nitrogen. The transmission probability of radiation shields has great influence on the performance of the cryo-condensation pump. The Monte-Carlo method is applied to simulate the trajectories of the deuterium molecules and to study the effects of the structure of the radiation shields on the transmission probability. By adding imaginary walls, the distribution of positions and flying directions of the molecules is presented. The results indicate that the uniformity of the molecules is the direct factor to influence the transmission probability.

1. Introduction

The Experimental Advanced Superconducting Tokamak (EAST) is one of the full superconducting tokamak that aims to achieve long-pulse operations (1000 s or more) to study the physics of steady-state operation for nuclear fusion sciences [1]. The neutral beam injector (NBI) has been employed on EAST for plasma heating and current driving [2–8]. The cryo-condensation pump is designed to create and maintain high vacuum required by beam generation and transportation in the NBI, for the cryo-condensation pump has advantages of large pumping, extreme high vacuum, non-pollution, etc. [9–12]. When gas is injected, higher pumping speed is able to provide higher vacuum, which is conducive to the performance of NBI. The transmission probability is proportional to the pumping speed of cryo-condensation pump.

Several methods have been applied to calculate the transmission probability, including the theoretical and numerical methods [13–19]. The theoretical methods are able to obtain exact solutions, and are usually applied to simple geometries, such as cylindrical, conical, and annular tubes [13]. The numerical methods are able to avoid the complex integral calculation [14–19]. With the development of the computer technology, the numerical methods can improve the accuracy and are applied to complicated geometries.

In this article, a numerical simulation code based on the Monte-Carlo method is developed to calculate the transmission probability. The relationship between the transmission probability and the structure of the cryo-condensation pump is studied. The results will provide guidance for the optimal design of the EAST-NBI system in the future.

2. Structure of cryo-condensation pump

Fig. 1 shows the approximate structure of NBI and the cryo-condensation pumps. High–energy ion beams from the ion source

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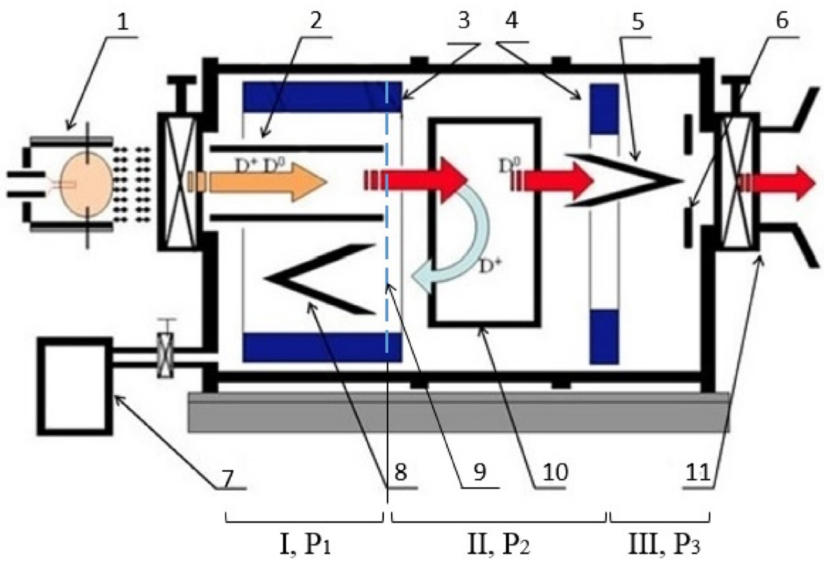

Fig. 1. The approximate structure of NBI and the pumps: (1) ion source, (2) neutralizer, (3) main cryo-condensation pump, (4) differential cryo-condensation pump, (5)calorimeter, (6) collimator, (7) auxiliary pump set, (8) residual ion dump, (9) gas baffle, (10) bending magnet, and (11) drift tube.

Table 1
The main parameters of the two cryo-condensation pumps.

	main and differential pump
Gas type	deuterium
Gas flow	4.89 Pa m^3/s
Regeneration time	$\sim 7*10^3$ s
Operating vessel pressure	$P_1 = 10^{-2}$ Pa, $P_2 = 4*10^{-3}$ Pa, $P_3 = 10^{-3}$ Pa
Pumping speed	main: $\sim 6*10^2$ m^3/s; differential: $\sim 4*10^2$ m^3/s
Overall dimension	main: cylinder, Φ2 m*1.6 m; differential: disk, Φ2 m

undergo atomic collision reactions in a gas cell named a neutralizer, in which part of the energetic ions turn into energetic neutral particles. Then the mixed particle beams are separated magnetically into ions and neutral particles by the bending magnet. Finally, the energetic neutral particles pass through the drift tube and inject into EAST, while the residual ions are dumped into a target (i.e. residual dump) and then pumped by the auxiliary pump set and the cryo-condensation pumps [8].

The cryo-condensation pumps are directly located inside NBI, rather than located outside and connected with NBI via a pipe. This arrangement is able to avoid the limitation of the pipe, and increase the pumping speed.

The requirements of vacuum pressure are different in different parts of NBI. Therefore, the cryo-condensation pumps in the EAST-NBI are designed to be differential in structure. They are composed of the main and the differential cryo-condensation pumps, and the former is split into two parts by a gas baffle. The distance between the gas baffle and the right endpoint of the main pump is about 0.46m. This design is able to provide three different types of vacuum environments: P_1, P_2, and P_3.

The main parameters of the two cryo-condensation pumps are shown in Table 1.

The main cryo-condensation pump is a cylinder, coaxial with the NBI, shown in Fig. 2. The radius is about 1m, and the depth about 1.6 m. The differential pump is a circular disk, the center of which is a hole for deuterium to fly through; both sides of the disk can pump the particles. The two pumps are not the same in shape; both are designed to achieve the biggest pumping area in their own places.

The main cryo-condensation pump is composed of 30 modules, which are distributed at the circumference. Each of the modules is

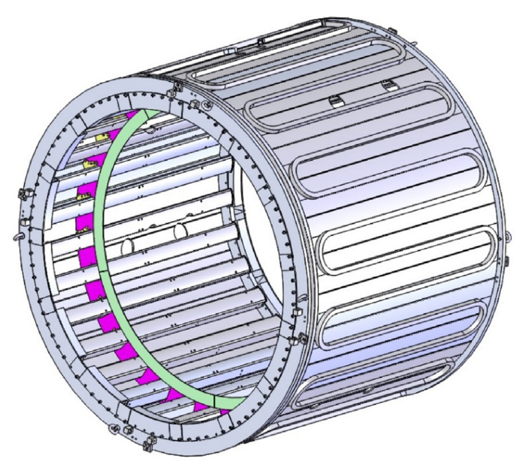

Fig. 2. The stereogram of the maim cryo-condensation pump.

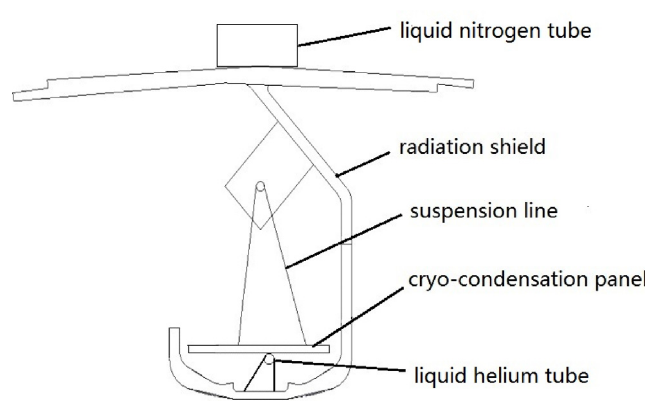

Fig. 3. The cross section of each module of the main cryo-condensation pump.

made up of a cryo-condensation panel cooled by liquid helium and a radiation shield cooled by liquid nitrogen, as shown in Fig. 3.

The cryo-condensation panel, which is the core component, is designed to pump the deuterium molecules by condensing them. When the molecules touch the panel, the panel has a cer-