THE M-C APPLICATION IN DESIGNING TAILORED CRYOPUMP USED IN CYCIAE-100 CYCLOTRON*

Suping Zhang #, Tianjue Zhang, Gaofeng Pan, Jiansheng Xing, Zhenguo Li, Fang Yang
CIAE, China Institute of Atomic Energy, Beijing 102413, China

Abstract

CYCIAE-100, a compact high intensity cyclotron, was selected as the driver for the Beijing Radioactive Ion Facility (BRIF). A pressure of 5×10^{-8} mbar is required to achieve acceptable beam losses in the CYCIAE-100 cyclotron. As the existing ports on the cyclotron valley are insufficient to provide enough pumping speed using commercially available pumps, a tailored cryopump with a pumping speed of 60000l/s was designed. Then based on the Monte-Carlo method, a mathematical model of molecular movement and collision between the tailored panels and its shield was developed. The ratio of molecular reflected to the baffle to molecular passing through the baffle is the capture probability on the panels. When taking the transmission probability of the chevron baffle, capture coefficient of cryopump can be got. It provides a reference to the shape and condensation area design of cryopump.

INTRODUCTION

CYCIAE-100, a compact high intensity and 4 sectors compact cyclotron, selected as the driver for the Beijing Radioactive Ion Facility (BRIF) [1], is under construction at CIAE, Beijing. The machine is designed to yield maximum energies of 100MeV for proton. Operative pressure has to be 5×10^{-8} mbar in order to reduce the beam losses due to particles collisions with the residual gas. Moreover the operative pressure has to be reached in less than 2 days pump down, to allow the machine to be used for nuclear physics experiments at least the day after the end of its maintenance. The CYCIAE-100 cyclotron has less than 10500l/s of conductance for external pumping units, and the total estimated out gassing is about 0.7 Pa l/s 25hrs after the pump down start, so that only an internal pumping system meets the operative vacuum requirements, leaving the task of fore pumping the vacuum chamber to external pumps. A large surface ($210m^2$) is exposed to vacuum although the accelerating chamber is small ($17m^3$). Moreover the vacuum is not a typical UHV requirement: many parts must be cleaned using solvents before and after their assembling, and a backing process is not practical on most accelerator components. Furthermore Viton sealing has been employed. A total pumping speed of about 120000l/s for condensative gas and about 20000 l/s for hydrogen has been estimated to gain the operative pressure, only four Φ500mm holes on the magnet yoke are used to achieve ultra-high vacuum, Fig. 1 shows the two Φ500mm holes on the top yoke. Four Φ500mm commercial pumps only have 40000L/s pumping speed, far from 120000l/s[2]. So two tailored cryopumps placed in the magnet valleys, 60000L/s pumping speed for condensation gas each, are designed for CYCIAE-100.

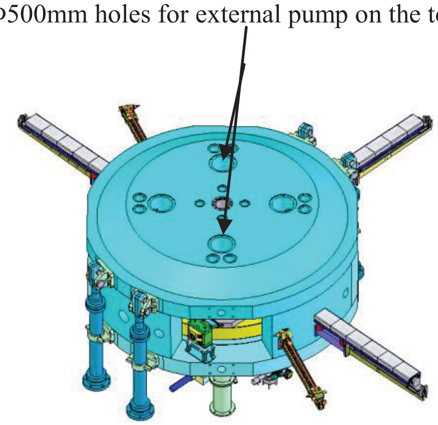

Figure 1: Two Φ500mm holes for external pump on the top yoke.

BRIEF INTRODUCTION OF DESIGNING TAILORED CRYOPUMP

The efficiency of tailored cryopump or total capture coefficient of tailored cryopump, c is given by the ratio of the actual pumping speed of tailored cryopump to the theoretical maximum(black hole) pumping speed S_{id}. Therefore actual pumping speed S is given by [3]:

$$S = c\cdot S_{id} = c\cdot\sqrt{\frac{RT}{2\pi M}}\cdot A \quad (1)$$

Where, A is a projected inlet area of cryopump, i.e. the area of cryopanel, T is temperature and M is molecular weight of gas being pumped. The total capture coefficient is a function of the internal cryopump geometry and the sticking probability of gas on cryopanel. Hence, one has to calculate capture coefficient for a given cryopanel geometry of cryopump. The total capture coefficient can be easily estimated for geometries, where inlet cross-setion, baffle an cryopanel are parallel, as in this type of tailored cryopump.

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#zhangsuping@impcas.ac.cn

Total capture coefficient, c can be expressed by Oately's law: [4]

$$\frac{1}{c} = \frac{1}{\Pr} + \frac{1}{w} - 1 \tag{2}$$

Where, w is the transmission probability of baffle, mounted on the inlet side of radiation shield and Pr is the capture probability of the gas particle at the cryopanel. This capture probability, Pr is a function of cryopanel geometry and sticking coefficients of particle on surface.

Monte-Carlo method is an efficient way to calculate capture probability on cryopanel and the transmission probability of the chevron baffle, so we can get Pr and w for different structure cryopanels with Monte-Carlo method, then chose the appropriate one, the c will be gained.

CALCULATING THE PR OF RECTANGLE CRYOPANEL

All the Monte-Carlo calculations are on the assumption that:

- The amount of being pumped gas particles is constant, that is to say that there is no absorption and degassing of the radiation shield. In other words, gas particles coming though baffles have two destinies that some are absorbed by cryopanel, and another are reflected.
- Cosine law is applied when gas particles collide with shield inner wall.
- All gas particles in cryopump are independent, in other words, there are no collision between gas particles.
- When gas particles collide with cryopanel, it will be absorbed by cryopanel.

Brief Review of Formulation

This formulation is analogous to that of thermal radiation exchange between diffuse surfaces of an enclosure. The molecular flux balance on kth surface will give following equations [5]

$$\mathrm{n}_k = n_{o,k} - n_{i,k} = n_{o,k} - \sum_{j=1}^{N} F_{kj} \cdot n_{o,j}$$
$$\Rightarrow n_k = \sum_{j=1}^{N} (\delta_{kj} - F_{kj}) \cdot n_{o,j} \tag{3}$$

$$\sum_{j=1}^{N} [\delta_{kj} - (1-)F_{kj}] \cdot n_{o,j} = n_{e,k} \tag{4}$$

In this calculation, one has to solve N matrix equatuion (4) for N surface elements of tailored cryopump to have outgoing molecular $n_{o,j}$ in term if molecular flux due to introduction of source $n_{e,k}$, sticking coefficient f_k and view factors $F_{k,j}$. Therefore, net molecular flux n_k can be found from equations (3) and $n_{o,j}$. If there are k entrance surface elements and m pumping surface elements of pump then the capture probability Pr of cryopanels can be written as:

$$P_r = \frac{\sum_{l=1}^{m} n_{i,j} \cdot A_l}{\sum_{j=1}^{k} n_{e,k} \cdot A_j} \tag{5}$$

Frame of Cryopanels in Shield

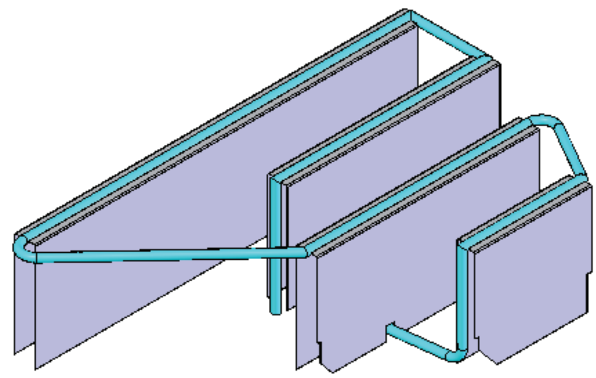

Figure 2: Cryopanels in shield.

For condensation gas, the area of cryopanel with a 60000l/s pumping speed is far bigger than the entrance of magnet valley (about 1.57m^2). In order to increase cryopanels absorption areas, a set of rectangle cryopanels shown in Fig. 2, is choosen to absorb condensation gases. Figure 3 shows the layout of reverse rectangle cryopanels and its radiation shield and spacers.

The Pr of Rectangle Cryopanels

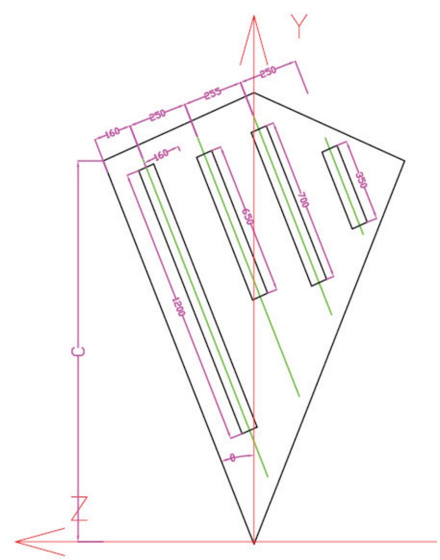

Figure 3: The layout of cryopanel, spacer and shield.

Monte-Carlo method usually consists of generating a sequence of molecule histories from a set of random numbers. The generation of the histories consists of the following processes. First, the space coordinates of a molecule at the shield opening are generated. In our

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tailored cryopump shown as Figure 3, the space coordinates of a molecule can be written as:

$$\begin{Bmatrix} x = H; \\ y = C \cdot \mathrm{Ran}() \\ z = C \cdot \tan\theta \cdot (2Ran() - 1) \end{Bmatrix} \quad (6)$$

(While $z > y\tan\theta$ or $z < -y\tan\theta$)

Where, H is height of the entrance, 450mm; θ is the half of the angle of magnet valley; C=1810mm is shown in Figure 3. Ran() is a random function. Then the direction cosines of the velocity vector of the molecule are generated, and can be written as：

$$\begin{Bmatrix} \alpha = -\cos\theta \\ \beta = \cos\varphi\sin\theta \\ \gamma = \sin\varphi\sin\theta \end{Bmatrix} \quad (7)$$

With the space coordinates and the direction cosines, it is determined whether the molecule has a collision with the shield inner wall or hits a cryopanel. If the molecule hits a shield inner wall, the coordinates of the collision point are calculated and new direction cosines are generated. It is again determined whether the molecule has a collision with the shield inner wall or hits a cryopanel. The molecule is thus followed from shield inner wall collision to wall collision until it hits a cyropanel. If the molecule hits a cryopanel, the history is terminated, and coordinates of a new molecule are generated.

After calculation, 82.8% molecules entering in entrance hit cryopanels, then are absorbed by cryopanels, that is mean Pr is 0.828.

THE CALCULATION THE w FOR LOUVER AND CHEVRON COMBINATION BAFFLE

In order to reducing the ambient radiation passing into cryopanel, a louver and chevron combination baffle is chosen. This combination baffle is composed of some louvers, four chevrons placed vertically against rectangle cryopanels, and three plates, Figure 4 shows the structure of combination baffle, and Fig. 5 is the section view.

The Result of w based Monte-Carlo Method

The w calculation is in the same way as Pr calculation. First, the space coordinates of a molecule at the baffle opening are generated. Then the direction cosines of the velocity vector of the molecule are generated. With the space coordinates and the direction cosines, it is determined whether the molecule has a collision with the baffle surface or enters in. If the molecule hits a baffle, the coordinates of the collision point are calculated and new direction cosines are generated.

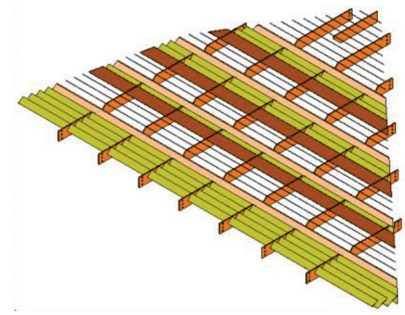

Figure 4: Frame of combination baffle.

It is again determined whether the molecule has a collision with baffle or enters in. The molecule is thus followed from baffle surface collision to baffle surface collision until it enters in. If the molecule enters in, the history is terminated, and coordinates of a new molecule are generated.

After calculation, 25.2% molecules pass through baffle, the else are thrown back, that is mean the transmission probability of baffle is 0.252

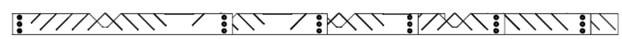

Figure 5: Section view of combination baffle.

SUMMARY

According to formula two, total capture coefficient of tailored cryopump is 0.239, therefore, for condensation gases, the actual pumping speed S for tailored cryopump with 2.23m^2 total cryopanels surface is 6342.3l/s. And two tailored cryopumps can satisfy the requirements of CYCIAE-100 vacuum system. Now two tailored cryopumps are under construction.

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