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# Transmission probability of the chevron baffle

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## Abstract

Baffles have been used in cryopumps to prevent 300 K thermal radiation from reaching freely cryopanels whose temperature must be kept steadily below certain levels(4 K, 20 K or something) depending on the gas to be pumped. There are two conflicting requirements in designing a baffle such that the transmission of particles(gas molecules) should be maximized, while that of the thermal radiation(photons) minimized. The transmission probability of gas molecules or photons through chevron type baffles, influenced by the detailed geometry of blades, the reflection mode, and the absorption property of the surface, was analyzed parametrically. The effects of geometrical discrepancy between the fabricated baffle and the designed one, resulting in unexpected deterioration in the performance of the baffle, were also investigated by taking into account the gaps(or overlaps) between the baffle blades and the asymmetry in the blade arms.

## 1. Introduction

In-vessel cyopumps have been used to pump mainly the hydrogen gas out of large vacuum chambers such as a tokamak vessel and a NBI tank [1-3]. The principle of the pumping action of the cryopump is the condensation of the gas on a 4 K metal surface cooled by liquid helium or the sorption on the activated carbon at below 20 K. In any case the cryopanel must be protected from 300 K radiation emitted from surrounding walls of room temperature to sustain the panel temperature low enough for adsorbing hydrogen gas molecules [4]. To reduce the heat load due to the thermal radiation the cryopanel is usually positioned inside a thermal shield(Fig. 1(a)). However, some part of the thermal shield should be removed to allow gas molecules to reach the cryopanel and then to make the panel operate practically as a pump. The above two contradictory requirements can be balanced by installing a component called baffle as a part of the thermal shield at the front of the cryopanel, which cuts off most thermal radiation as well as provides a path to the panel for gas molecules.

The baffle consists of parallel blades of linear or circular shape between which passages of dual property, nearly opaque to the thermal radiation but partially clear to the gas, are formed. The point of designing the baffle is to increase the transmission of gas molecules as highly as possible, while to limit the transmission of the thermal radiation(photons) to a certain level depending on the required cryopanel temperature and the available cooling power. It is very natural that the transmission probability has the same trend for the gas molecules and the photons if considering only the baffle geometry. However, the reflection mode and the absorption property of the blade surface may influence selectively the transmission of the gas and that of the thermal radiation.

In this paper the influence of the geometry and the surface condition of the blades on the transmission probability of the gas molecules and the photons through standard and modified chevron baffles is parametrically studied using the Monte Carlo method [5-7]. The effect of geometrical discrepancy between a fabricated baffle

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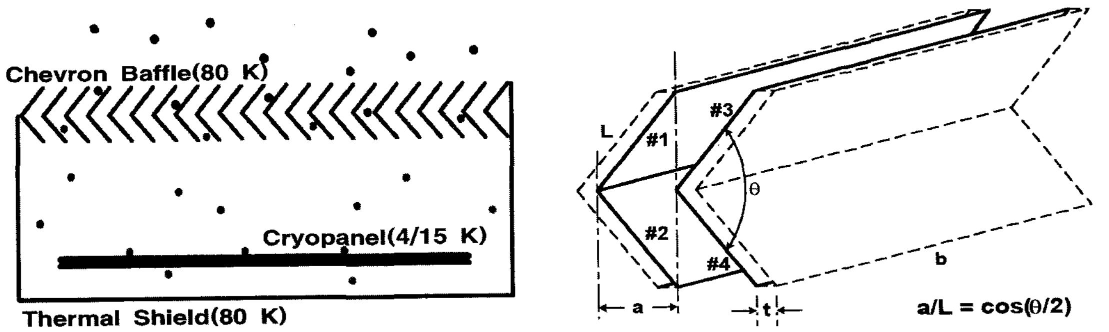
and a designed one is also investigated by taking into account the gaps between baffle blades and the asymmetry in blade arms.

## 2. Conventional chevron blade

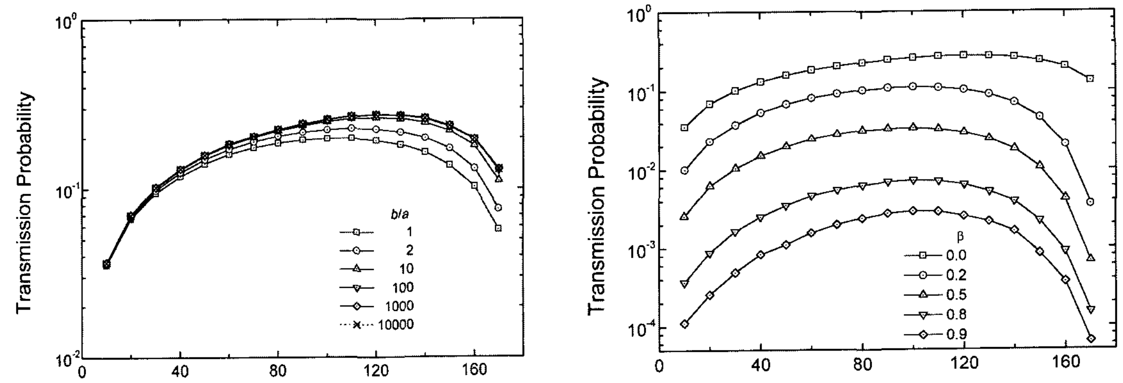
Figure 1(b) shows a model of the basic chevron element composed of four active planes(#1 ~ #4) of two blades facing each other to simulate a normal chevron baffle by the Monte Carlo method. The transmission probability of particles through the space between the blades depends on the reflection mode; diffuse or specular, the absorption property of the blade surface; absorbent or non-absorbent, and the geometry of the blade defined by the blade angle $\theta$.

Figures 2(a) and 2(b) show the transmission probability of the chevron element as a function of the blade angle assuming the diffuse reflection a) for several aspect ratios $b/a$(blade axial length/blade distance, Fig. 1(b)) from 1 to 10000 and b) for various surface absorptivity $\beta$ from 0 to 0.9. The transmission probability increases gradually as the aspect ratio changes from 1 to 100 and saturates above it at any blade angle, though the increasing rate is very low at much smaller angles(Fig. 3(a)). This dependency of the transmission probability on the aspect ratio is attributed to the collision of particles with two side walls of the chevron element, that is, the influence of the side wall can not be neglected at small aspect ratio



(a) (b)

Fig. 1 (a) Chevron baffle used in a cryopump and (b) model of the chevron element for Monte Carlo simulation.



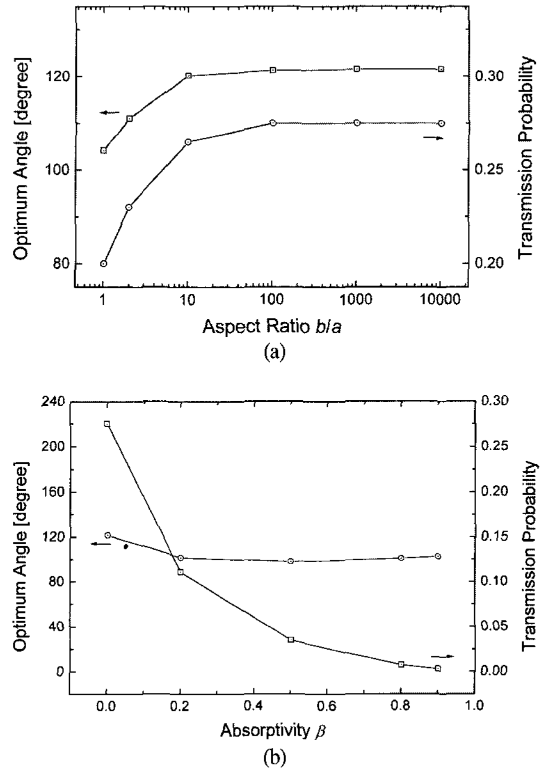
(a) (b)

Fig. 2 Transmission probability of the chevron element assuming diffuse reflection for (a) several aspect ratios at $\beta$=0 and (b) various surface absorptivity at b/a=$10^5$.

less than 100. All simulations, if not stated otherwise, are carried out with a fixed aspect ratio of $10^5$.

At small blade angles there occur a lot of back reflection of particles at the first collision with the blade especially on the #3 plane in Fig. 1(b), while at large angles particles experience many collisions before transmitting the chevron element through the narrow channel. Therefore, the transmission curve in Fig. 2 has a broad peak whose position corresponding to the optimum blade angle changes slightly with the aspect ratio and the surface absorptivity as shown in Figs. 3(a) and 3(b). The maximum transmission probability is 0.275 at the blade angle of 120 degrees when the surface is not absorptive ($\beta$ =0).

In Fig. 3(b) the maximum transmission probability decreases exponentially as the surface absorptivity increases, where the optimum blade angle becomes around 100 degrees rather than 120 degrees. The maximum transmission probability is in the range of $10^{-3}$ at the absorptivity of 0.9, which indicates that blackening of the baffle surface is an effective way of protecting the cryopanel against the thermal radiation penetrating the baffle.



(a)

(b)

Fig. 3 Variation of the maximum transmission probability and corresponding blade angle for diffuse reflection as functions of (a) the aspect ratio and (b) the surface absorptivity.

In Fig. 4 variations of the transmission probability for various surface absorptivity assuming the specular reflection are given. With the specular reflection on the absorptive surface two or three peaks are found in the transmission curves because of frequent back reflection to the entrance at the first collision around the blade angle of 90 degrees, which dominates for high absorptivity, and at the second and the third collision around 60 degrees, which is noticeable for zero or low absorptivity. A common tendency of the transmission curves in Fig. 4 is, in spite of minor oscillations, a steady increase with the blade angle due to the intrinsic forward directional property of the specular reflection, except that the transmission of particles is almost shut off at the blade angle near 180 degrees where the space between the blades is too narrow to pass.

The transmission of particles experiencing the specular reflection is higher than that with the diffuse reflection in the full range of the blade angle for zero surface absorptivity as shown in Fig. 5. That is based on the

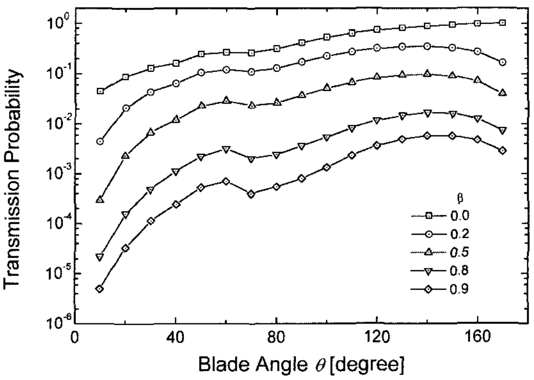


Fig. 4 Transmission probability of the chevron element assuming specular reflection for several absorptivities.

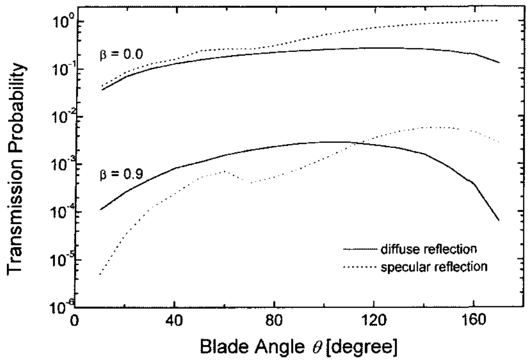


Fig. 5 Comparison between transmission probability with diffuse reflection and that with specular reflection.

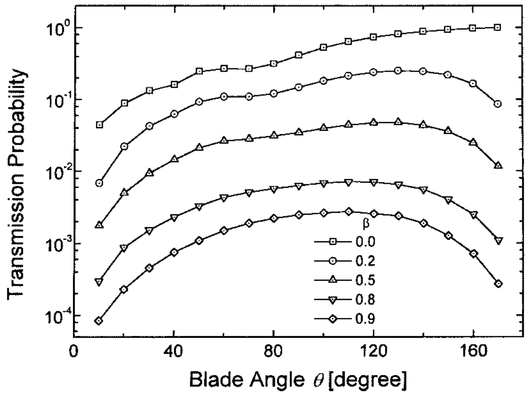


Fig. 6 Transmission probability of chevron element assuming mixed reflection mode.

fact that the average number of collisions with the surface in the specular reflection mode is lower than that in the diffuse reflection mode. For example, when the surface absorptivity is zero at the blade angle of 120 degrees, the average number of collisions is 4.6 for specular mode and 5.7 for diffuse mode. At large blade angles the transmission of particles reflected specularly is always larger than that of diffusely reflected ones regardless of the surface absorptivity, because a large fraction of particles direct forward after collisions, though the collision number goes up, in the specular mode. For reference, the average number of collisions is 1.5 with the specular reflection and 1.2 with the diffuse reflection when the surface absorptivity is 0.9 at the blade angle of 120 degrees.

It is usually assumed that gas molecules undergo the diffuse reflection on a physical plane of most surface conditions, mirror-polished, mechanically roughened, chemically blackened and so on, while the photons are reflected specularly on the smooth surface or diffusely on the rough surface. It can be safely considered that a practical surface, especially the blackened one, has a combined reflection property for the thermal radiation, some fraction diffusely and others specularly. Figure 6 shows, as an example, the transmission probability calculated assuming that the thermal radiation of a fraction equal to the surface absorptivity is reflected diffusely. As expected easily, at low surface absorptivity the transmission curve is similar to the specular case, while at high absorptivity to the diffuse case. In a further part of this paper it is assumed that the absorbent surface has normally the absorptivity of 0.9 and particles(possibly photons) experience wholly the diffuse reflection on the surface.

## 3. Chevron baffle

### 3.1 Effect of the blade thickness

A baffle is an array of chevron blades set up in a regular pattern inside a frame as shown in Fig. 1(a). In the simulation model of the chevron element(Fig. 1(b)) only the distance (*a*) between two blades, not the thickness (*t*) of the blade, is considered. The transmission probability of the baffle ($P_b$) is basically the same as that of a chevron element ($P_e$) except a factor corresponding to the ratio of the effective entrance area to the whole baffle area including the space occupied by blades. Using the notations in Fig. 1(b) we obtain the following result assuming that gas molecules and photons incident on the flat end of the blades, due to back reflection or absorption, do not contribute at all to the transmission.

$$P_b = \frac{a}{a+t} P_e \tag{1}$$

In Fig. 7 the transmission probability of the baffle is

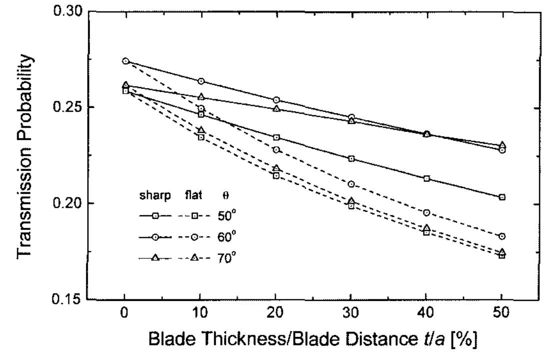


Fig. 7 Transmission probability of the normal baffle (dotted) considering blade thickness and of the sharp-edged baffle(solid) for $\beta$=0 as a function of normalized blade thickness.

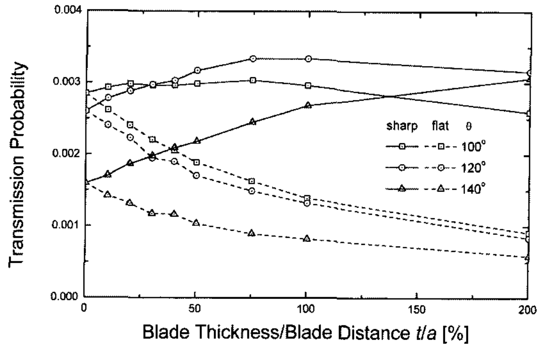


Fig. 9 Transmission probability of the normal baffle (dotted) considering blade thickness and of the sharp-edged baffle(solid) for $\beta$=0.9 as a function of normalized blade thickness.

plotted as a function of $t/a$ for the non-absorbent surface ($\beta$=0). There is a greater drop in the transmission through the baffle with the thicker blades. If the blades of 120 degrees are made of metal plates of 3 mm thickness ($t=3/\sin 60^\circ \sim 3.5$) and the period of the blade array is 30 mm ($a+t=30$), the practical transmission probability reduces by about 15% compared with the simulated one(values at $t/a$=0).

If the flat end of the blade is modified to form a sharp edge like as Figure 8, the transmission through the baffle can be enhanced considerably because particles hitting the end of a blade are not completely rejected. Graphs of the transmission probability of the baffle with the sharp-edged blades for $\beta$=0 are also given in Fig. 7. For $t/a$=0.12 as above example, the reduction in the transmission probability is moderated to merely 5% in this case. The decrease in the transmission probability of the sharp-edged chevron blades lowers for the larger blade angle, where the angle of the fabricated ridge($\phi$ in Fig. 8) does not deviate greatly from the original blade angle ($\theta$).

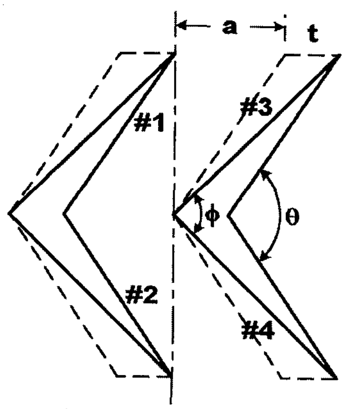


Fig. 8 Model of the sharp-edged chevron element.

Figure 9 shows the transmission probability of the sharp-edged chevron baffle for three blade angles when the blades have absorbent surfaces of $\beta$=0.9. Contrary to the case of $\beta$=0, the transmission probability even increases as the blades thicken($\phi$ enlarges) at the same $\theta$, which is caused by some increase in the fraction of particles directing to the exit from #1 and #2 planes (Fig. 8) and penetrating the baffle without further collision with absorptive surfaces. For very thick blades, however, the transmission probability falls down again, because the number of particles striking the #1 and #2 planes diminishes comparing with that striking the #3 plane and then reflecting backward.

## 3.2 Effect of blackening the surface

The baffle is usually blackened to absorb the thermal radiation emitted from surrounding structures and should be cooled down to the cryogenic temperature by removing the thermal load absorbed on the blackened surface not to become a new emitter of the thermal radiation to

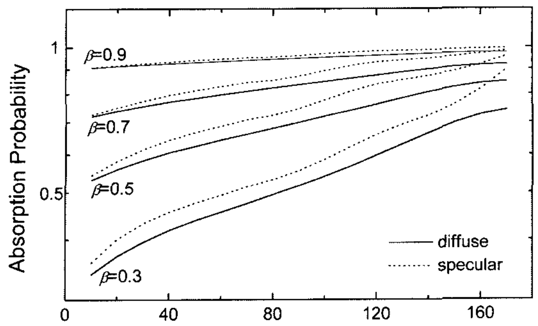


Fig. 10 Absorption probability of the chevron element with absorbent surface.

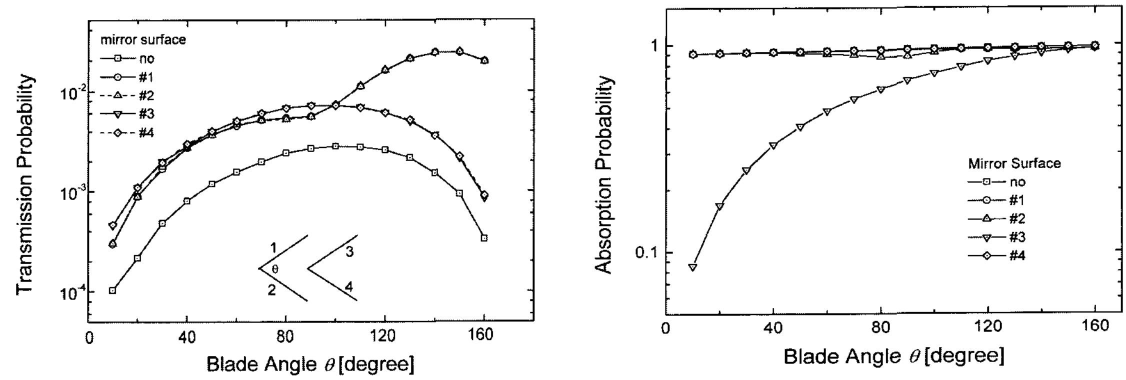
the cryopanel. Figure 10 shows the absorption probability ($P_{am}$) of the thermal radiation in the chevron element depending on the blade angle and the surface absorptivity when whole surface is blackened. The absorption increases monotonically with the blade angle regardless of the reflection mode because of more frequent collisions with the blades at the larger angle. The absorption of the radiation assuming the specular reflection is always higher than that with the diffuse reflection.

The absorption probability of the baffle composed of blackened blades is given by Eq. (2) when taking into account the thickness of the blades.

$$P_a=\frac{a}{a+t}P_{am}+\frac{t}{a+t}\beta=\frac{aP_{am}}{a+t}\left(1+\frac{t}{a}\frac{\beta}{P_{am}}\right) \qquad (2)$$

If the flat ends of blades are totally reflective, $\beta$=0 in Eq. (2) and $P_a=P_{am}a/(a+t)$. The relation of $\beta<P_a<P_{am}$ is satisfied because $P_{am}$ is always higher than the surface absorptivity $\beta$ (Fig. 10). The relation $P_{am}=\beta$ is fulfilled only on a perfectly flat plane of the surface absorptivity $\beta$. The heat load to the absorptive baffle of 1 $m^2$ by 300 K thermal radiation(emission rate is ~400 $W/m^2$) is, if $\beta$>0.5, roughly a few hundred watts regardless of the blade angle.

In a commercial cryopump the baffle is usually blackened partially to reduce the thermal load of 300 K radiation by enhancing back reflection. For this purpose the surface facing the entrance port is usually kept highly reflective, while others are blackened. It is unavoidable that any reflective surface, regardless of the location, raise the transmission of the thermal radiation more or less. Figures 11(a) and 11(b) show, respectively, the transmission probability and absorption probability of the thermal radiation in the chevron element one of whose four planes is not blackened when the absorptivity of the blackened surface is 0.9. When #3 surface (refer to Fig. 1(b)) is reflective and the others are blackened, at the blade angle of 120 degrees, the transmission increases about 2.5 times, while the absorption decreases by 30%, comparing with those of wholly blackened. Making #1 or #4 surface reflective has no significant effect on the absorption of the thermal radiation because most photons



(a)

(b)

Fig. 11 (a) Transmission probability and (b) absorption probability of the chevron element one of whose surface is highly reflective.

are removed at the first or second collision with other blackened surfaces when the surface absorptivity is 0.9. In Fig. 11(a) the transmission probability curves indicate intrinsic non-directional characteristics of the transmission of particles in the channels which have geometrical symmetry(#1 and #2 surfaces or #3 and #4 surfaces in this case).

## 3.3 Effect of the gap

In the simulation model of Fig. 1(b) the line connecting both ends of a chevron blade of any angle is assumed to coincide with the nose of the next blade. However, it is practically impossible to make the blade array free from unexpected gaps which are critical to the penetration of the thermal radiation through the baffle. Usually, therefore, the blades are set up to overlap a bit with each other in spite of reduction in the transmission of gas molecules. Sometimes blade gaps are unintentionally formed due to imperfect fabrication and/or inaccurate assembly, causing an increase in the directly transmitting radiation.

Figure 12 shows the transmission probability of the chevron baffle which has gaps or overlaps for various surface absorptivity $\beta$. At small gaps the change of +10% results in the increase of 5.6% in the transmission for $\beta$=0 and 141% for $\beta$=0.9, while at small overlaps the change of +10% makes the decrease of -6.1% and -27.5% respectively. The increase of the gap size affects the transmission more strongly on the absorptive surface than on the non-absorptive one. For high surface absorptivity, if there is a gap between blades the transmission of the thermal radiation is governed mainly by direct penetration which exerts much large influence in several orders comparing with the case of no-gap or overlap where the collision followed by absorption or reflection is the main factor of controlling the transmission. Therefore, by these two factors of different effect the transmission curve has a discontinuity in the gradient at the boundary of the gap side and the overlap side. For low surface absorptivity the transmission is determined principally by collision and the influence of the gap is relatively weak, and then the transmission curve looks smooth even at the boundary.

## 3.4 Effect of asymmetry of the blade

If the length of an arm of a chevron blade becomes different from standard one, intentionally or accidentally, a gap or an overlap is formed between vicinity blades. An increase of the arm length corresponds to an overlap of blades, while a decrease of it to a gap. Figure 13 shows the transmission probability of the chevron baffle which has blades of asymmetric arms. A small change in the blade arm length is roughly equivalent to a half of the change in the gap, because linear shift of a blade

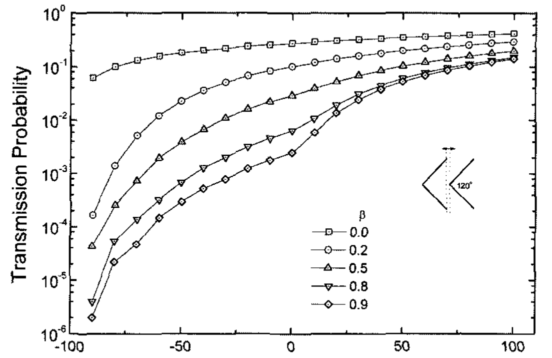


Fig. 12 Transmission probability of the chevron baffle with gaps or overlaps.

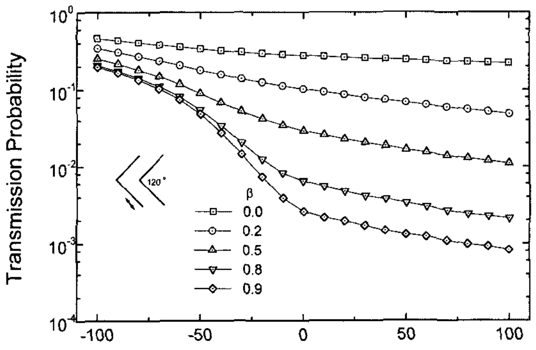
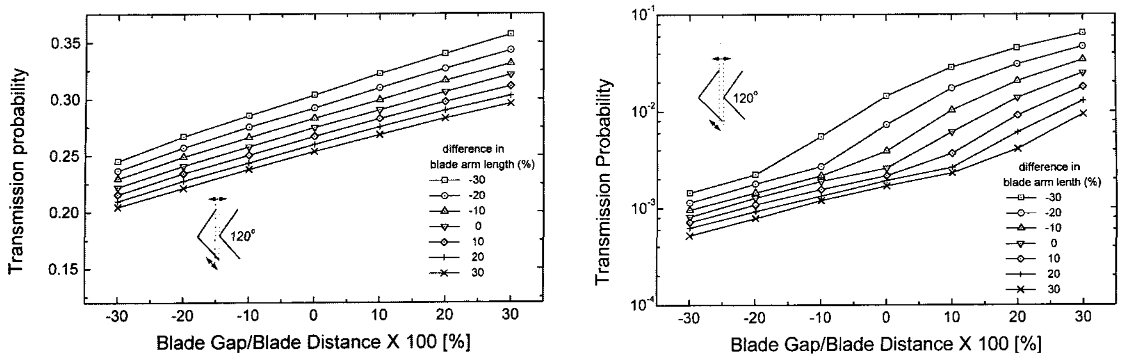


Fig. 13 Transmission probability of the chevron baffle with asymmetric blades.



(a) (b)

Fig. 14 Transmission probability of the chevron baffle with both of gaps (or overlaps) and asymmetries for a) $\beta$=0 and b) $\beta$=0.9.

to make a gap is effectively equal to changing in both arms of the blade in the same rate. Shortening an arm by 10% results in the increase of 3% in the transmission for $\beta$=0 and 49.6% for $\beta$=0.9, while lengthening the arm by 10% causes the decrease of -2.8% and -16.5% respectively.

### 3.5 Combined effect of gap and asymmetry

Figures 14(a) and 14(b) show the transmission probability of the chevron baffle which has not only the gaps in the blade array but also asymmetries in the blade arms for $\beta$=0 and $\beta$=0.9 respectively. For small changes the resultant effect of combination of the gap(or overlap) and the asymmetry is roughly the algebraic summation of each contribution. If an arm of the blade shortens by 10% and the size of the gap is also 10% of the standard blade interval the transmission increases by 8.9% for $\beta$=0 and by 295% for $\beta$=0.9, while lengthening the arm by 10% and increasing the overlap to 10% of the blade interval result in the change of -8.8% and -29.6% respectively.

## 4. Conclusions

In this paper a large variety of practical topics were discussed concerning the chevron baffle used in a cryopump to prevent 300 K thermal radiation from reaching freely a cryopanel whose temperature must be kept steadily below certain levels depending on the gas to be pumped.

The transmission probability of gas molecules or photons through a chevron type baffle, influenced by the detailed geometry including the blade angle, reflection mode(diffuse or specular) and absorption property of the blade surface, was parametrically analyzed using the Monte Carlo method. The effect of the gap between baffle blades and the asymmetry in blade arms, formed intentionally or unintentionally during fabrication and/or assembly, were also investigated.

The results obtained in this paper will be utilized in designing the cryosorption pump of 500000 L/s to test the KSTAR NBI system in the 60 $m^3$ vacuum tank.

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