Pumping Speed Near the RF Window of the CESR SRF Cavity

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February 27, 1998

Abstract

The net pumping speed near the RF window of the SRF cavity for CESR luminosity upgrade is estimated. A comparison of the estimation for the current pumpinging configuration and a proposed configuration is made to understand how much gain we can get to improve the net pumping speed in the vicinity of the RF window. The pumping speed due to the cryopumping from the wave guide at 4.2 K is also estimated.

1 Current Configuration of the Window Pumping System

Currently two ion pumps, pumping speed of each 60 *liter/sec*, are used to evacuate the vicinity of the RF window of the SRF cavity. Each pump is connected with the wave guide through one branch of a T-shaped elbow. For the sake of a better microwave propagation, pumping port on the wave guide wall is configured as 79 small straight round holes, called as 'shower drain', rather than one big hole. The arrangement pattern of the holes is depicted in Fig. 1. For each pumping branch the net pumping speed can be calculated by recognizing a serial connection of the pump, the elbow, and the shower drain. The total net pumping speed of the whole exhausting system will be simply the double of that of one branch due to a symmetric arrangement of the two pumps.

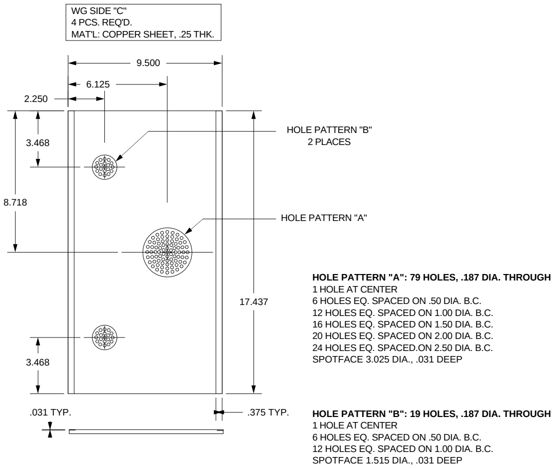

Figure 1: Structure of the shower drain

At present stage accurate information about the gas species near the window are still not quite clear, so the pumping speed estimation in this

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note refers to that for the air at room temperature.

1.1 Conductance of the shower drain

The conductance of each small hole can be expressed as

$$C_i = 11.7\alpha A, \tag{1}$$

where C_i is the conductance of each hole in *liter/sec*, α is the transmission probability of the hole, and A is the area of the orifice on the upstream side in cm^2. The depth and diameter of each small hole are $l = 0.25''$ (0.635 *cm*) and $d = 0.187''$ (0.475 *cm*) respectively, so the aspect ratio of the orifice is $l/d = 1.34$. According to table 1 [1], the transmission probability is $\alpha = 0.44$, as a result C_i is 0.9118 *liter/sec* and the total conductance of the shower drain amounts to 72 *liter/sec*.

$$C_{shower\ drain} = \sum_{i=1}^{79} C_i = 72\ liter/sec, \tag{2}$$

1.2 Conductance of the elbow (for one branch)

The structure of the elbow is sketched in Fig. 2. For one branch of the elbow, the axis length of the short and long arms are $LA = 7.012''$ (17.81 *cm*) and $LB = 11.375''$ (28.89 *cm*) respectively. The radius of the duct is $R = 1.437''$ (3.65 *cm*). To simplify the calculation, we divide the long arm of the elbow into two parts, one part is in the same length ($B' = 17.71$ *cm*) with that of the short arm to form a symmetric elbow, and the other part is just a straight pipe (and its length is $B'' = 28.89 - 17.81 = 11$ *cm*).The whole elbow is equivalent to a symmetric elbow connected in series with a round pipe.

Table 1: Transmission probability for round pipes (Source: Ref. [1])

l/d	a	l/d	a
0.00	1.00000	1.6	0.40548
0.05	0.95240	1.7	0.39195
0.1	0.90922	1.8	0.37935
0.15	0.86993	1.9	0.36759
0.2	0.83408	2.0	0.35658
0.25	0.80127	2.5	0.31054
0.3	0.77115	3.0	0.27546
0.35	0.74341	3.5	0.24776
0.4	0.71779	4.0	0.22530
0.45	0.69404	4.5	0.20669
0.5	0.67198	5.0	0.19099
0.55	0.65143	6.0	0.16596
0.6	0.63223	7.0	0.14684
0.65	0.61425	8.0	0.13175
0.7	0.59737	9.0	0.11951
0.75	0.58148	10.0	0.10938
0.8	0.56655	15.0	0.07699
0.85	0.55236	20.0	0.05949
0.9	0.53898	25.0	0.04851
0.95	0.52625	30.0	0.04097
1.0	0.51423	35.0	0.03546
1.1	0.49185	40.0	0.03127
1.2	0.47149	45.0	0.02796
1.3	0.45289	50.0	0.002529
1.4	0.43581	500.0	0.26479×10^{-2}
1.5	0.42006	5000.0	0.26643×10^{-3}

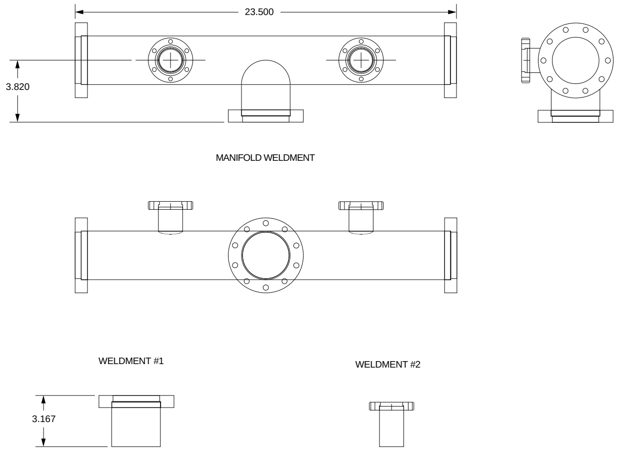

Figure 2: Structure of the elbow

For the symmetric elbow, $LA/R = B'/R = 4.88$, so according to Fig. 3 the transmission probability is $\alpha_1 \approx 0.2$. For a round pipe of 11 *cm* long with a diameter of 7.3 *cm*, the transmission probability is $\alpha_2 = 0.4$ (see Table 1). The total transmission probability of the elbow can be derived from the following equation with the end effect taken into account,

$$\frac{1}{\alpha} = \frac{1}{\alpha_1} + \frac{1}{\alpha_2} - 1. \tag{3}$$

We have $\alpha = 0.15$ so the conductance of one branch of the elbow amounts to

$$C_{Elbow} = 11.7\alpha\pi R^2 = 73.4\ liter/sec. \tag{4}$$

1.3 Net pumping speed of the window evacuating system

The net pumping speed of one branch of the pumping system can be derived from the following equation,

$$\frac{1}{S} = \frac{1}{S_p} + \frac{1}{C_{Elbow}} + \frac{1}{C_{Shower\ drain}}, \tag{5}$$

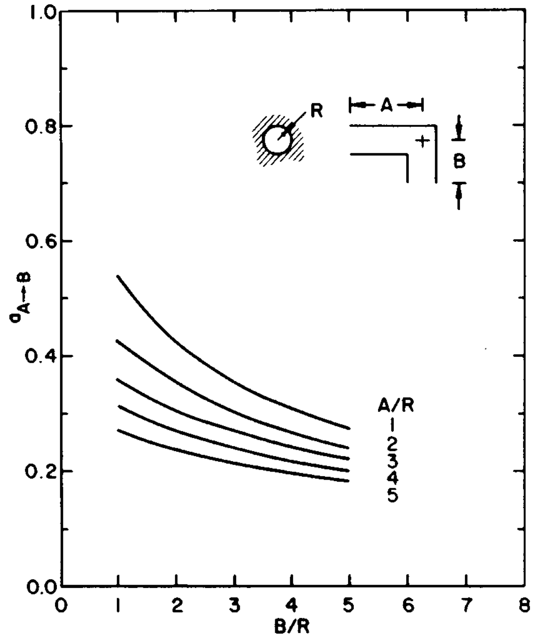

Figure 3: Transmission probability for elbows (source Ref. [1])

where S is the net pumping speed of one branch of the system, C_{Elbow} is the conductance of one branch of the elbow, $C_{Shower\ drain}$ is the conductance of the shower drain, and S_p is the pumping speed of the ion pump. Note that the end effect of the shower drain is not taken into account because of the fact that the dimensions on both sides of the hole are much larger than that of the orifice.

Substituting Eq. 3 and Eq. 4 into Eq. 5 we have the net pumping speed of one branch of the system, $S = 22.6\ liter/sec.$ For there are two pumping branches, the net pumping speed of the whole window evacuating system is

$$S_{net} = 2S = 45\ liter/sec. \tag{6}$$

From Eq. 5 it is easy to tell that for the current configuration the net pumping speed of the system is to the same extent limited by the ion pump, the conductance of the elbow, and the conductance of the shower drain.

2 Proposed Configuration of the Window pumping System

2.1 Conductance of the shower drain with tapered pumping holes

According to Eq. 5, to improve the net pumping speed we need to improve the conductance of the shower drain, the conductance of the elbow and the pumping speed of the ion pump. For the solely sake of improving the conductance of the shower drain, the larger the diameter of each small hole the higher its conductance. However, we should be cautious of the RF leakage with larger holes on the shower drain. For the above consideration it comes out to be a good idea to taper the holes downstream the molecular flow while keeping the diameter of the hole on the RF side unchanged. (We may need to round the edges resulting from tapering of the holes to avoid possible excessive RF arcing in the region of the shower drain.)

If we keep the pattern and number of the holes on the shower drain the same as before, the maximum usable space will allow a 0.5″ (1.27 *cm*) orifice diameter ($2R_1$) downstream the tapered hole. The diameter of the orifice on the RF side ($2R_2$) is unchanged, 0.187″ (0.475 *cm*), and this results a taper angle of 33° considering a depth of 0.25″ (0.635 *cm*) of the hole (L). The aspect ratio of the tapered hole is

$$\frac{L}{R_2} = \frac{R_1}{R_2} = 2.67, \tag{7}$$

and according to Fig. 4 the transmission probability from plane R_1 to plane R_2 is

$$\alpha_{12} = 0.13. \tag{8}$$

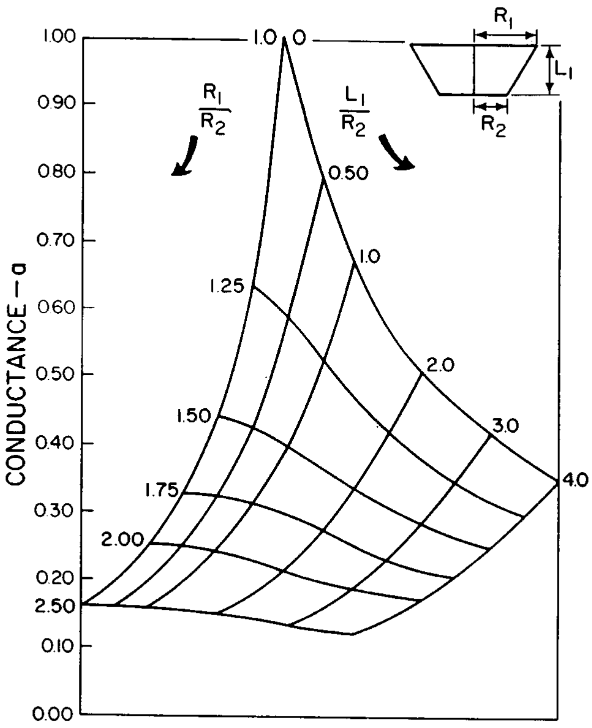

Figure 4: Transmission probability for tapered holes (source Ref. [1])

The transmission probability from plane R_2 to plane R_1 can be derived from

$$\alpha_{12} A_1 = \alpha_{21} A_2 \tag{9}$$

where A_1 and A_2 are the orifice area on the downstream and upstream of the tapered hole respectively.

From Eq. 9 we have $\alpha_{21} = 0.93$, so the ratio of transmission probability of the tapered hole over the straight hole is

$$\frac{\alpha_{Tapered\ hole}}{\alpha_{Straight\ hole}} = \frac{0.93}{0.44} = 2.1. \tag{10}$$

Now the conductance of the shower drain is

$$C_{Shower\ drain/tapered\ hole} = 72 \times 2.1 = 152\, liter/sec \tag{11}$$

Substituting Eq. 11 into Eq. 5 we get the resulting pumping speed of one branch of the system is $S = 27\ liter/sec$, and the net pumping speed of the whole exhausting system is

$$S_{net/tapered\ hole} = 27 \times 2 = 54\ liter/sec \tag{12}$$

From Eqs. 6 and 12, the gain of the net pumping speed we get by tapering the holes on the shower drain is

$$\frac{\Delta S_{net}}{S_{net}} = \frac{S_{net/tapered\ hole} - S_{net/straight\ hole}}{S_{net/straight\ hole}} = 20\%. \tag{13}$$

2.2 Net pumping speed dependence on the pumping speed of the ion pumps

From Eq. 5 we know that the net pumping speed is limited almost to the same extent by the conductance of the shower drain, the conductance of the elbow, and the pumping speed of the ion pumps. In section 2.1 we have studied the net pumping speed improvement by tapering the pumping holes on the shower drain, and by this way we can get a 20% gain in the net pumping speed. Another approach to improve the net pumping speed is to replace the current ion pumps with pumps of higher pumping speed. The dependence of the net pumping speed on the pumping speed of the ion pumps for different shower drain configurations are shown in Fig. 5.

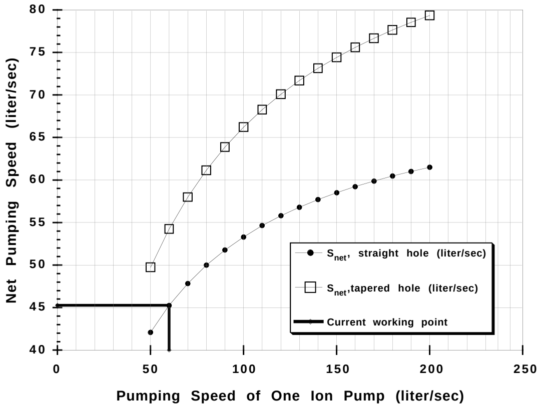

Figure 5: Dependence of the net pumping speed on the pumping speed of ion pumps

To further effectively improve the net pumping speed requires the modification of the structure of the elbow to improve its conductance.

3 Cryopumping by the Cold Part of the Wave guide

Because some part of the wave guide and the whole cavity are immersed in the helium vessel of the cryostat, the RF window is subject to a cryopump working at 4.2 K. In this section, we will estimate the cryopumping speed near the RF window. In the following discussions we assume that

(1) The conductance of the wave guide elbow is the same as that of a straight wave guide with the same axis length,

(2) Cryocondesation is the prevailing cryopumping procedure and the condensation coefficient is 1 regardless the thickness of the condensed layer (this is true for most room temperature gas species [2]),

(3) All the estimations refer to the gas species of air at room temperature.

The width and height of the wave guide are $AW = 17.125''$ (43.3 *cm*) and $BW = 4.00''$ (10.2 *cm*) respectively and the axis length of the wave guide from the window pumping port to the helium vessel is $L = 52.5''$ (133.35 *cm*). From these data we have the aspect ratio of the wave guide

$$\frac{AW}{BW} = 4.25 \quad \text{and} \quad \frac{L}{BW} = 13. \tag{14}$$

According to Fig. 6 the transmission probability of the wave guide is

$$\alpha = 0.15, \tag{15}$$

so we get the conductance of the wave guide from the window pumping port to the helium vessel

$$C = 11.7\alpha A = 775 \ liter/sec \tag{16}$$

where $A = 43.3 \times 10.2 = 441.66 \ cm^2$ is the area of the wave guide cross-section.

The total inner surface area of the Nb wave guide, which is at 4.2 K, are about 2500 cm^2, as a result the cryopumping speed due to the cold wave guide is

$$S_{Cryo} = 11.7 \times 2500 = 29,000 \ liter/sec. \tag{17}$$

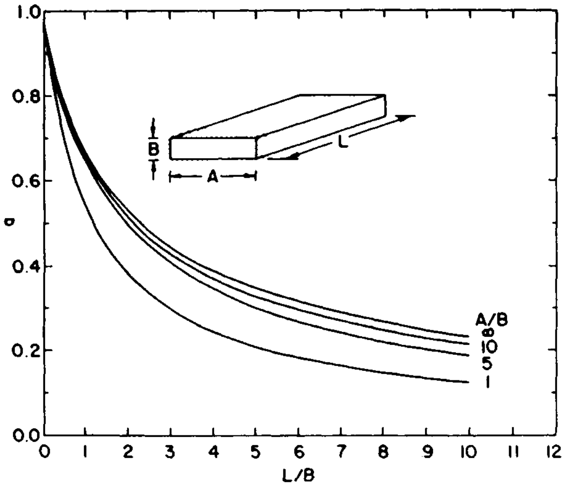

Figure 6: Transmission probability for rectangular ducts (source Ref. [1])

From Eqs. 16 and 17 we have the net cryopumping speed is about

$$S_{net/Cryo} = 775 \ liter/sec, \tag{18}$$

which is dominated by the conductance of the wave guide. Note that the cryopumping resulted from the cavity is neglected in the above estimation because the area of the coupler tongue, which is between the wave guide and the cavity, is much smaller than the inner surface area of the Nb wave guide.

4 Discussions and Conclusions

By comparing Eqs. 6, 12 and 18 we can see that the pumping speed by cryopumping is much higher than that of the ion pumps. To reduce gas condensation on the inner surface of the wave guide and the cavity we need to improve the net pumping speed of the window exhausting system further.

As the ending up of this note we address some discussions related with the above estimation,

- All the pumping speeds are estimated on a basis of static analysis. However this may not necessarily true when applying for abrupt vacuum actions, which usually occur in the window processing. For this reason the estimation results in this note should be used with caution.

- There is a temperature gradient along the wave guide, which will influence the estimation of the cryopumping speed. For example, some part of the wave guide extending from the helium vessel is bellow 20 K. It is most likely that nitrogen, carbon monoxide, oxygen and more condensable gases are pumped by this part, rather than by the 4.2 K Nb wave guide, to partial pressure bellow 10^{-8} torr [3] .

References

[1] John F. O'Hanlon, *A User's Guide to Vacuum Technology*, second edition, John Wiley & Sons, 1989.

[2] Rene A Haefer, *Cryopumping-Theory and Practice*, Oxford Science Publications, 1989.

[3] David H. Holkeboer et., *Vacuum Technology and Space Simulation*, American Institute of Physics, 1993.