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Conductance pipe for the VIRGO IVC

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CHANGE RECORD

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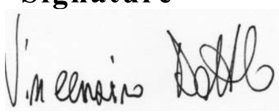
C. Bradaschia V. Dattilo F. Frasconi P. Mugnier Z. Zhang		
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Introduction

In this note we describe some technical aspects of the IVC (Intermediate Vacuum Chamber) conductance pipe, its function inside the suspension vacuum vessel, as well as the suitable requirements to reach the right level of vacuum in the Virgo tall towers.

In addition the requirements and constraints concerning the SuperAttenuator (SA) and the IVC which have been used on the conductance pipe design, are presented. Finally, a preliminary analysis on the dependence of injected flux (from upper to lower tower) from the conductance pipe dimensioning is performed. According to this, it should be possible to minimize the flux by means of a proper dimensioning of the conductance pipe.

I. Conductance pipe function

The big difference on outgassing rate expected from the SA upper part (inverted pendulum and seismic filters) and that coming from the payload (marionette, reference mass and mirror), dictate the vacuum compartimentation of the tall towers.

The beam compartment containing the payload is thus isolated from its corresponding SA compartment by the IVC. Each of these compartments is pumped by its own pumping system. In this way it is possible to reach the required pressure (total pressure: 10^{-9} mbar, HC partial pressure: 10^{-13} mbar) [1] inside the payload compartment, while in the SA compartment only 10^{-6} mbar is required.

These two compartments are put in communication by means of a vertical conductance pipe, located in the centre of the separating horizontal roof, which allows the passage of the suspension wire and of the electrical cables connecting the marionette to the steering filter (named filter F#7).

Of course, this passage has to be designed keeping at a minimum value the upper to lower tower injection rate. For this reason, an intermediate vacuum chamber between the payload compartment and the SA compartment has been implemented (Fig.1): the conductance of the pipe (~1 l/s is the minimum value coming from several constraints) should be decreased by a factor roughly equal to the intermediate pumping speed S_I ($S_I \cong 200$ l/s).

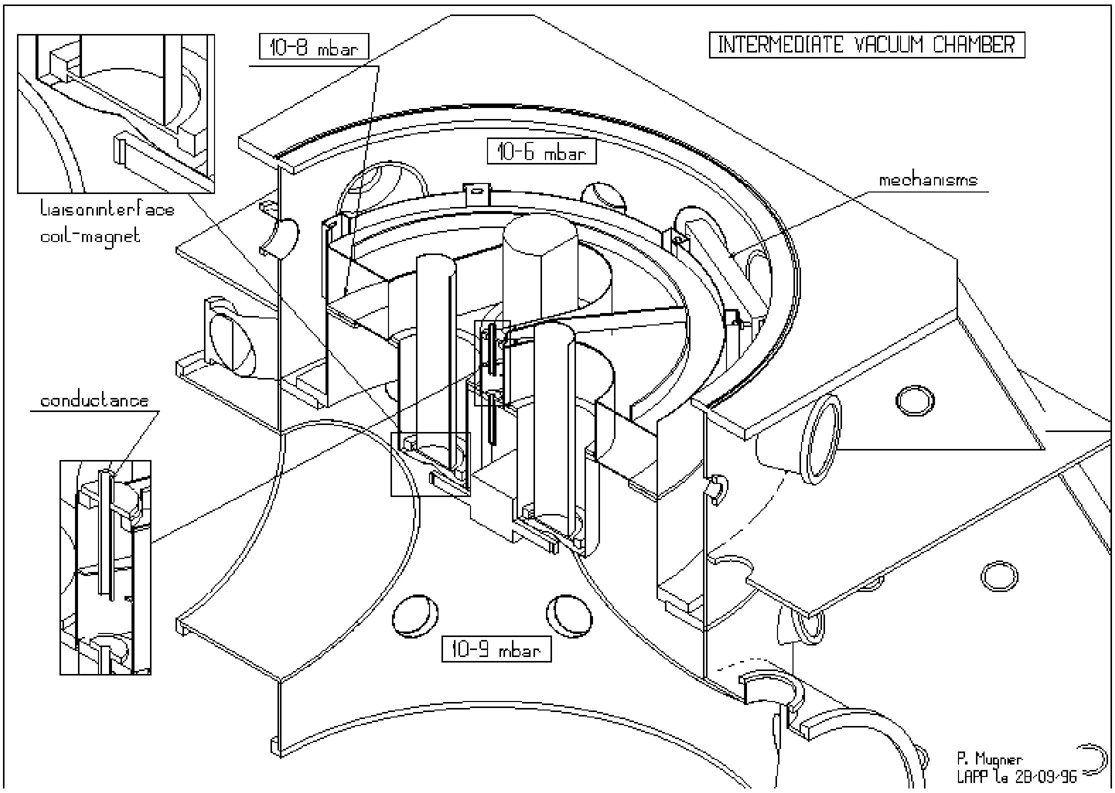

Fig.1: View of the IVC and of the conductance pipe.

II. Requirements

The starting point of the pipe design is the definition of the main dimensions, that are the total length and the inner diameter. This dimensioning is subjected to several constrains and requirements, listed below:

1. The injected flux from the upper part to the lower one and hence the conductance value should be kept as low as possible. A reasonable

value of the conductance is about a few litres/sec (when no intermediate pumping is acting).

2. The assembly consisting in the suspension wire wrapped with the electrical cables (described in [2]) and passing through the pipe, has an outer diameter of 6.4 mm (Fig.2). The value of 6.4 mm is the minimum one needed to arrange the 18 electrical wires and the suspension wire, considering that this last one has a nail head with a diameter of 6 mm. This assembly can be regarded as a solid cylinder, concentrically placed inside the pipe.
3. The horizontal displacement range of the suspension wire/cables assembly has to be ± six/seven mm wide to allow the horizontal chain positioning and the possibility of horizontal excitation for transfer function measurements.
4. In order to avoid any contact with the electrical cables used in the assembled wire, the pipe has to be shorter than the wire/cables (at least 80 mm). The length of the assembly has been fixed to 500 mm. This value is dictated by the length of the intermediate suspension wire (603 mm) and by the need in operating on the wire junction boxes during the payload installation. The length of 603 mm for the wire is in turn dictated by the distance between F#7 and marionette (Fig.3).
5. In order to allow the intermediate pumping, the pipe has to be split in two shorter pipes, leaving a vertical gap between them (Fig.3). In this way it is possible to evacuate through the IVC pumping the main part of the flux coming from the upper tower.

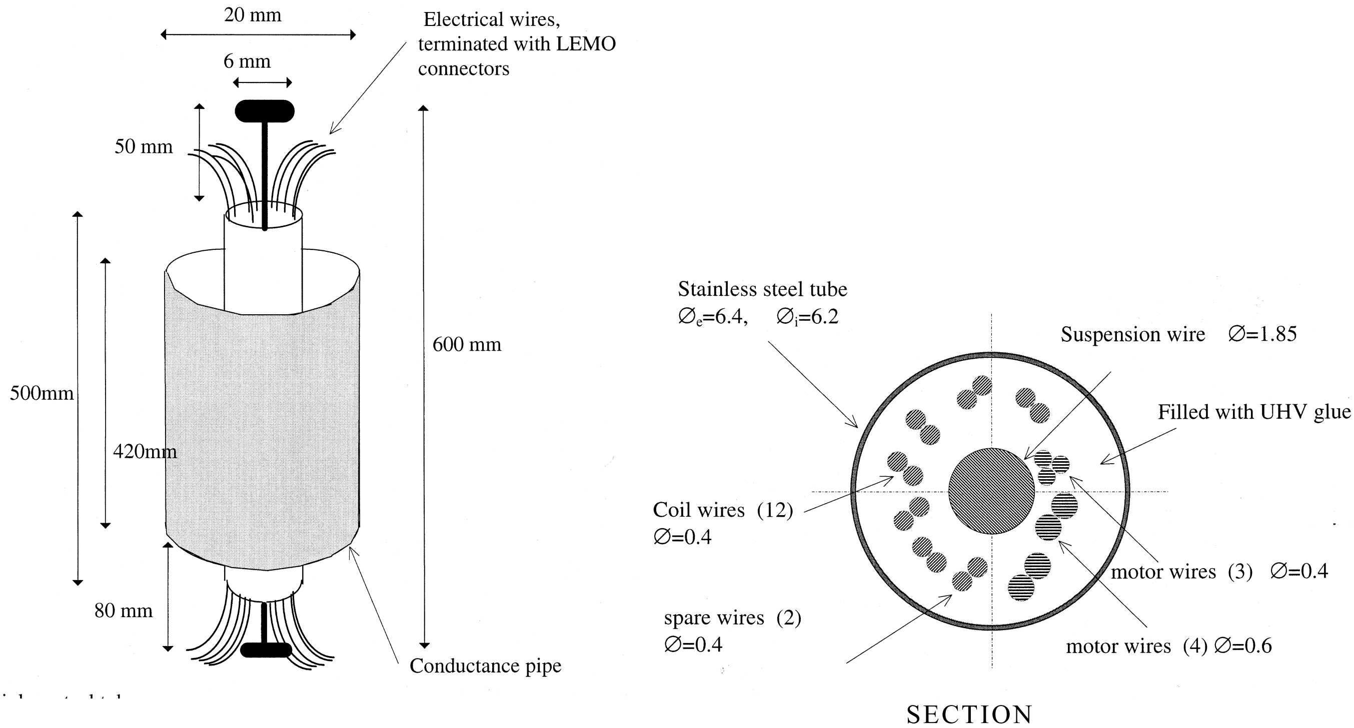

Fig.2: Schematic of the suspension wire/electrical cables assembly (not in scale).

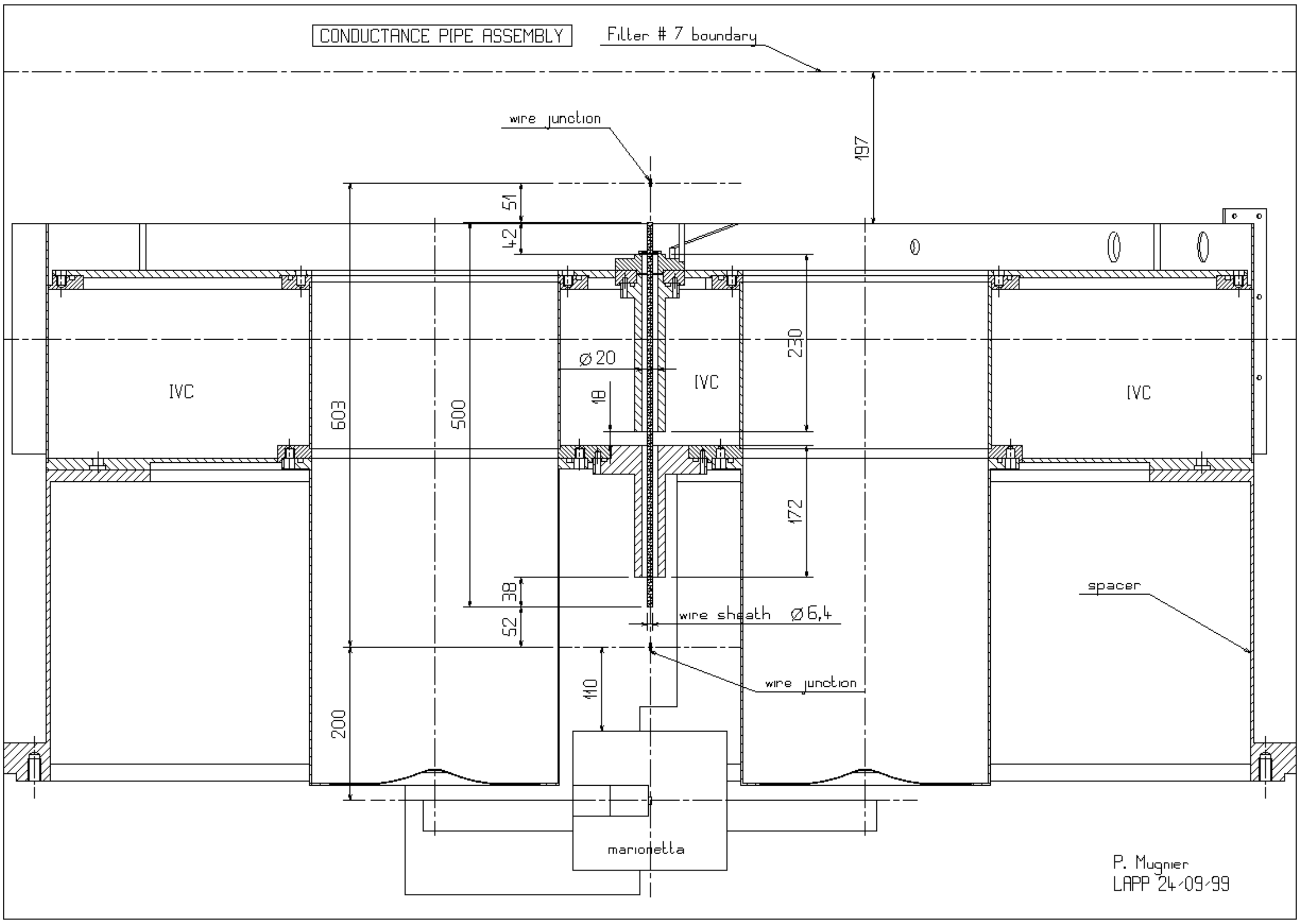

Fig.3: Schematic section of the IVC, the conductance pipe, the suspension wire.

III. Design considerations

The dimensioning is performed in 2 steps: in the first step we define the length and the diameter of the whole pipe, while in the second step we define the lengths of the two pipes.

In order to fulfil condition #1, it is intuitive that we have to choose the maximum length and the minimum diameter for the pipe, compatibly with all the other constraints. The value of the conductance, indeed, for a rectilinear pipe with a ring section is expressed by [3]:

$$C = 3.81 \cdot \sqrt{\frac{T}{M}} \cdot \frac{(D_P - D_A)^2 \cdot (D_P + D_A)}{L} \cdot K \qquad \text{l/s} \qquad (1)$$

where:

- D_P, D_A, L are the pipe diameter, the wire/cables assembly diameter, the length of the pipe, respectively (expressed in cm);
- T is the absolute temperature;
- M is the molecular mass;
- K is a corrective factor depending on the ratio D_A/D_P:

D_A/D_P	0	0.259	0.500	0.707	0.866	0.966
K	1	1.072	1.154	1.254	1.430	1.675

If, as in our case, the pipe is short (L<20 D_P), it is not longer possible to neglect the resistance of the pipe aperture with respect to the resistance of the pipe. These two resistances have to be considered in series. The conductance of an aperture is independent from its form and is expressed as [3]:

$$C = \frac{1}{4}\cdot\sqrt{\frac{8RT}{\pi M}}\cdot A = 3.64\cdot\sqrt{\frac{T}{M}}\cdot A \qquad \text{l/s} \qquad (2)$$

where A is the area of the aperture, expressed in cm^2.

By considering the series of the two above conductances, the following expression for the conductance of a short pipe (having a ring section) is obtained:

$$C = 3.81\cdot\sqrt{\frac{T}{M}}\cdot\frac{(D_P - D_A)^2\cdot(D_P + D_A)}{0.75\cdot(D_P + D_A)\cdot K + L}\cdot K \qquad \text{l/s} \qquad (3)$$

Let's denote:

- C_U, L_U the conductance and the length of the pipe between the upper vessel and the IVC;
- C_L, L_L the conductance and the length of the pipe between the IVC and the lower vessel;

In our case the total value C_T of the conductance between the upper and the lower vessel is given by the series of the two conductances:

$$C_T = C_U // C_L = \frac{1}{\frac{1}{C_U}+\frac{1}{C_L}} = 3.81\cdot\sqrt{\frac{T}{M}}\cdot\frac{(D_P - D_A)^2\cdot(D_P + D_A)}{1.5\cdot(D_P + D_A)\cdot K + L_U + L_L}\cdot K =$$

$$= 3.81\cdot\sqrt{\frac{T}{M}}\cdot\frac{(D_P - D_A)^2\cdot(D_P + D_A)}{1.5\cdot(D_P + D_A)\cdot K + L_T - L_G}\cdot K \qquad (4)$$

where $L_T=L_U+L_G+L_L$ is the total length required for the two pipes when mounted on the IVC, and L_G is the vertical gap between the two pipes.

The value of C_T as a function of L_T and D_P, is plotted in Fig.4. Considering in the same figure the dashed area, inside which reasonable dimensions are included, one can see that C_T is more dependent on D_P than on L_T.

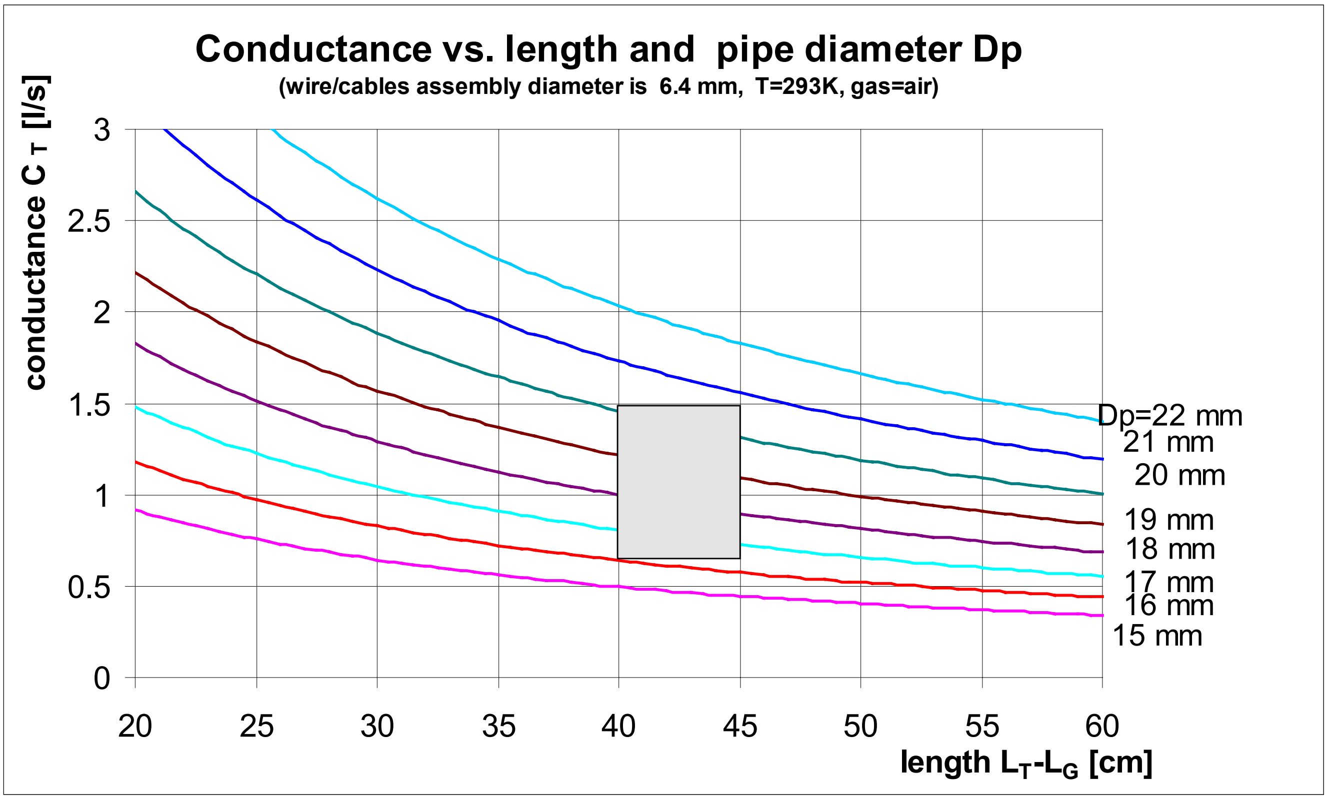

Fig.4: Conductance dependence on the total length and on the pipe diameter. The dashed rectangle includes reasonable dimensions.

Now it is clear that in order to minimise the C_T value:

- The length L_T must be maximised. Taking into account the conditions #4 and #5, we have set L_T=420 mm and L_G=18 mm.
- The pipe diameter D_P must be minimised. Taking into account the condition #3, we have set D_P=20 mm.

By using these values, the resulting C_T for air is equal to 1.45 l/s, at room temperature and with the intermediate pumping turned off.

In the second step, the lengths L_U and L_L have to be defined.

In this step, it is no longer accurate to argue in terms of conductance value, but it is better to consider the upper to lower tower injected flux, keeping in mind the goal of minimising it. In fact, the presence of a pumping in the IVC makes no longer the two pipes in series and there is no longer a so direct relationship between the injected flux and the value of the total conductance.

To calculate the upper to lower tower injected flux, it could be convenient to consider the analogous electrical scheme of our system, as reported in Fig.5. The assumption of the superposition of the effects has been made, in order to consider the outgassing flux coming from the upper tower and its effect in the lower tower, independently from the outgassing fluxes generated in the IVC and in the lower tower.

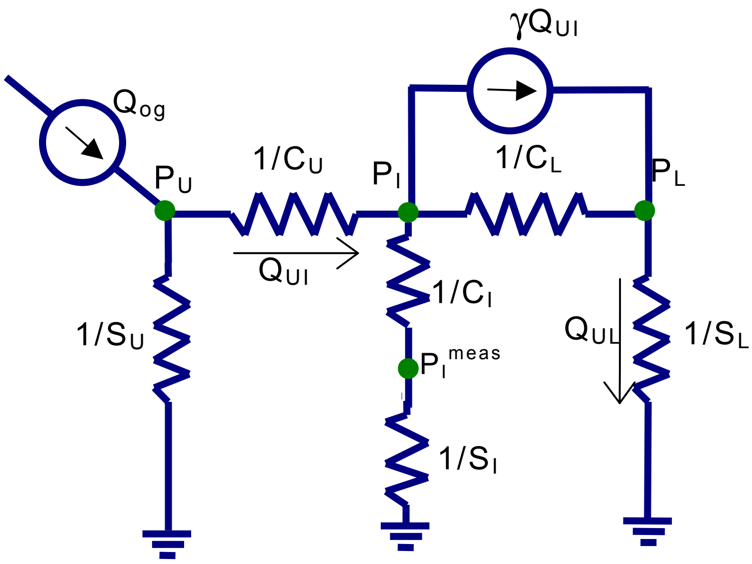

Fig.5: The electric analogous schematic of the vacuum system.

The symbols used in Fig.5 are listed below, with the corresponding typical value in parenthesis (values from [1]):

Q_{og}: total outgassing flux in the upper tower (10^{-3} mbar·l/s);
Q_{UI}: upper tower to IVC injected flux (~10^{-6} mbar·l/s);
Q_{UL}: upper to lower tower injected flux (~10^{-8} mbar·l/s);
S_U: upper tower pumping speed (10^3 l/s);
S_I: IVC pumping speed ($2 \cdot 10^2$ l/s);
S_L: lower tower pumping speed ($3 \cdot 10^3$ l/s);
P_U: upper tower pressure (10^{-6} mbar);
P_I: IVC injected pressure (~$10^{-7} \div 10^{-8}$ mbar);
P_I^{meas}: IVC injected pressure at the measuring point (pressure gauge close to the pump (~10^{-8} mbar);

P_L: lower tower injected pressure (~10^{-12} mbar);

C_I: conductance between the IVC and the intermediate pump (due to the particular geometry of the IVC, $1/C_I$ is not negligible with respect to $1/S_I$);

γ: coefficient that accounts for the beaming effect caused by the upper pipe. It depends on the sizes of the pipes and it represents the percentage of flux Q_{UI} directly injected to the lower pipe.

Applying the Current Kirckhoff Law to the above circuit:

$$\begin{cases} Q_{OG} - P_U S_U - (P_U - P_I) C_U = 0 \\ (P_U - P_I) C_U - P_I S_I' - (P_I - P_L) C_L - \gamma (P_U - P_I) C_U = 0 \\ (P_I - P_L) C_L - P_L S_L + \gamma (P_U - P_I) C_U = 0 \end{cases} \tag{5}$$

and solving for the pressures P_U, P_I, P_L, it is then possible to express the equivalent conductance C_{EQ} (represented in Fig.6) and the transfer function Q_{UL}/Q_{og} as a function of the other parameters of the system:

$$C_{EQ} = \frac{Q_{UL}}{P_U - P_L} = C_U S_L \frac{C_L + \gamma S_I'}{C_L S_I' - \gamma S_I' + C_L S_L + (1-\gamma) C_U S_L + S_I' S_L} \tag{6}$$

$$\frac{Q_{UL}}{Q_{og}} = \frac{P_L S_L}{Q_{og}} =$$

$$= C_U S_L \frac{C_L + \gamma S_I'}{S_I' C_L C_U + C_L C_U S_L + C_U S_I' S_L + C_L C_U S_U + C_L S_I' S_U + C_L S_L S_U + C_U S_L S_U (1-\gamma) + S_I' S_L S_U} \tag{7}$$

where $S_I' = S_I // C_I$ (~100 l/s).

The two latter expressions can be simplified considering that: $S_U \sim S_L \sim 10 \cdot S_I' \sim 10^3 \cdot C_U \sim 10^3 \cdot C_L$.

$$C_{EQ} \cong \frac{C_L C_U}{S_I'} + \gamma C_U \tag{8}$$

$$\frac{Q_{UL}}{Q_{og}} \cong \frac{C_L C_U}{S_I' S_U} + \gamma \frac{C_U}{S_U} = \frac{C_{EQ}}{S_U} \tag{9}$$

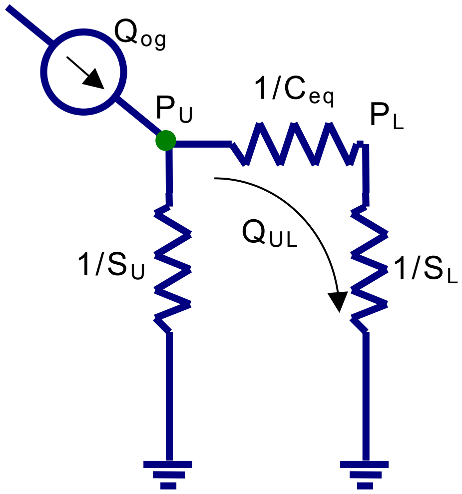

Fig.6: The electric analogous schematic of the simplified vacuum system.

In order to determine the value of the two conductances C_U and C_L, and hence their respective lengths C_U and C_L, it is convenient to express them in terms of the total conductance $C_T = C_U // C_L$:

$$C_U = \alpha C_T \qquad C_L = \frac{\alpha}{\alpha - 1} C_T \qquad \alpha > 1 \qquad (10)$$

By substituting the latter expression in (8):

$$C_{EQ} = \left(\frac{\alpha^2}{\alpha - 1} \frac{C_T}{S_I'} + \alpha\gamma \right) C_T \qquad (11)$$

Now, we have to determine the α value for which there is a minimum for C_{EQ}, and hence, from (9), a minimum in the injected flux Q_{UL} from the tower upper part to the lower one.

This calculation is rather difficult due to the scanty knowledge of the coefficient γ. In fact, the percentage of flux Q_{UI} directly injected to the lower pipe, is expressed by the coefficient γ. Unfortunately, an expression for γ as a function of the geometrical parameters(L_U, L_L, L_G, D_A, D_P,), and therefore as a function of α, does not exist.

Even in the case of a more simple shape (for example a cylindrical pipe), the density distribution and directional streaming of molecules inside and outside the pipe is the solution of an integral equation [4]. In this simple case too, the numerical solution of the integral equation represents a difficulty. In this case the results of the calculations [5] are displayed in a series of diagrams (Fig.7) clearly illustrating the narrow and more pointed beam pattern emerging from a pipe as soon as its ratio length/radius increases; in contrast, a short pipe (i.e. thick orifice) shows a relatively small departure from the spherical cosine distribution (Knudsen Law).

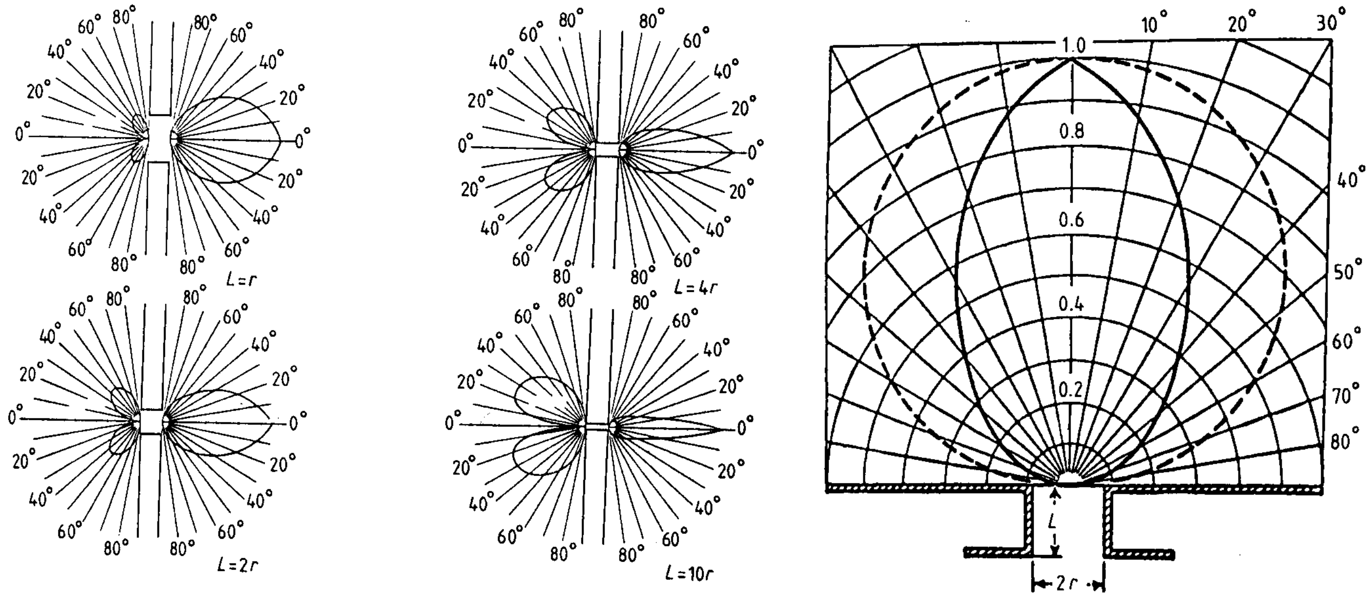

Fig.7: Polar diagrams of gas flow at the entrance and exit of cylindrical pipes for different length/radius ratios, compared with flow through an orifice (dashed line).

At the moment, one of the authors (Z.Zhang) is developing a computer simulation for the determination of γ.

However, it is equally interesting to plot C_{EQ} versus α (Fig.8), even if γ is considered as an α independent parameter. It is evident that only in the case γ=0, C_{EQ} has a minimum for α=2 (i.e. upper and lower pipes with the same length). While, for the more real cases, the minimum in C_{EQ} is achieved when α<2 (i.e. with the upper pipe <u>shorter</u> than the lower pipe).

In addition, an increase of L_G may help to reduce this beaming effect.

In Fig. 9, the technical drawing of the two pipes, currently utilised, is represented. Each pipe is flanged, and its connection way is conceived taking into account the assembly steps of the SA. In fact, it is foreseen the possibility to mount/dismount the pipes after the IVC positioning and the F#7 positioning (with wire/cables assembly connected), acting from the lower tower side.

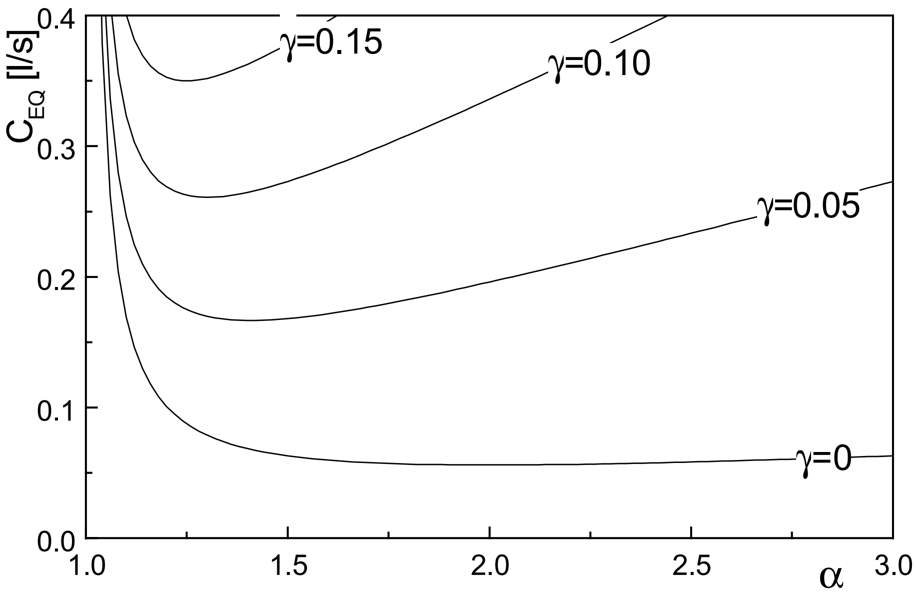

Fig.8: C_{EQ} vs. α and γ. For these qualitative purposes, γ has been considered not depending on α. A value of C_T equal to 1.4 l/s has been assumed.

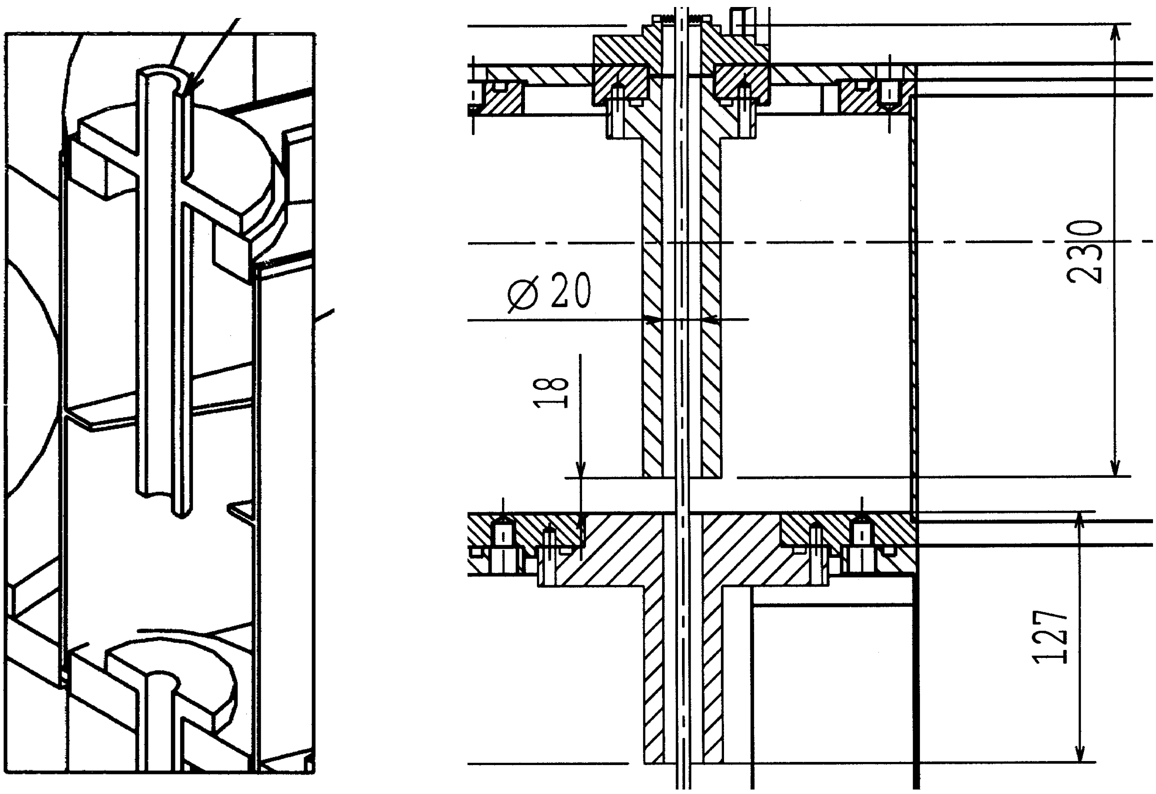

Fig.9: Drawing of the two pipes

IV. Preliminary measurements

Vacuum measurements have been performed by the Vacuum Group on the towers having the IVC positioned, before the SA assembly phase. The conductance pipe dimensions are: L_U=230mm, L_L=127mm, L_G=18mm, D_P=20mm, D_A=6.4 mm ($\alpha \cong 1.6$).

For the measurement purposes, the suspension wire assembly has been replaced by an aluminium cylinder. The obtained results are similar for the various towers.

In the case of the Beam Splitter tower, several measurements recorded during the pumping, yielded to the following values for the conductance:

C_T [l/s] (intermediate pumping OFF)
1.4
1.4
1.6
0.9

C_{EQ} [l/s] (intermediate pumping ON)
0.25
0.26
0.33
0.30

From these data it appears that the presence of the IVC produces a decrease in the total conductance by a factor about 5, only.

However, these measurements are not to be considered conclusive due to some technical difficult encountered. In fact, up to now, it has not been possible to carry out an initial bakeout, to reduce at a minimum level the outgassing of the lower part and of the IVC. In this way, it should be avoided that these outgassing fluxes partially mask the upper to lower tower injected flux. To overcome this undesired situation, a selected gas (Argon) has been inserted in the upper tower, so that an acceptable accuracy in the measurement could be obtained. Unfortunately, the used gas is an inert gas and the intermediate pump is a ionic pump, hence in this case there is a poor adsorption[1] of the Ar molecules by the honeycomb cathode of the pump. Consequently the velocity S_I of the pump is well below the nominal value. The result is a small effect in reducing C_{EQ}. It is foreseen to perform again the measurements by using another gas, as soon as an IVC will be available for such a test.

Another difficult in performing the measurement is due to the fact that the conductance between upper and lower is also contributed through the gliding area of the IVC. In the first prototype, the conductance through the gliding area was 2.4 l/s [6], which is higher than the

[1] In fact, the Titanium atoms emitted by sputtering from the anode, react weakly with the Ar molecules and hence the conveyor effect of the titanium atoms towards the cathode is low.

conductance through the pipe! For the second prototype it was improved to 0.03 l/s, and 0.03 l/s/ with IVC pumping [7].

V. Conclusions

The steps for the dimensioning of the conductance pipes of the IVC have been described. Respecting the constraints imposed by the SA and by the IVC, the total length L_T set for the two pipes when mounted on the IVC is 420 mm and their diameter D_P is 20mm.

The definition of the lengths $L_{U,}$ L_L and L_G is not concluded, due to the difficulties in the calculations coming from the undesired phenomenon of the pipe molecular beaming and to some technical problem in performing reliable measurements. At this level of knowledge it is only possible to state that, for a given intensity of the beaming the minimum in the equivalent conductance C_{EQ} is achieved by making the upper pipe shorter than the lower one (Fig.8). By using the results of the simulation and calculations, presently in progress, it should be possible to define those lengths, which minimise C_{EQ} and the upper to lower injected flux.

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