MODELLING OF THE PRESSURE DISTRIBUTION IN THE CYCLOTRON CENTRAL REGION

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The vacuum module simulating the geometrical shape of the central region (PIG ion source – puller) was manufactured to investigate the geometrical factor influence on the pressure distribution. The results of the pressure measurements and the estimation of the transmission factor are presented.

Introduction

Beam loss due to charge exchange with the residual gases plays a significant role in the cyclotrons when heavy ions or H^-/D^- are accelerated. For this reason the gap's dimensions, the radial dimension and the pump positions should be optimised. In 1965 Ehler described the performance of his H^- PIG source [1]. Small internal H^-/D^- sources based on Ehler's PIG source design have been used in many medical cyclotrons needing only 50-200 μA of external beam. It has been noticeable that some of them use special geometrical configuration of puller. This geometrical configuration has been chosen to improve some properties of puller such as optical property, mechanical stability and heat conductivity. In this paper we investigate the pressure distribution in such puller's geometry and calculate the transmission factor due to charge exchange. A model representing this geometry has been manufactured and was compared with other configurations to investigate the transmission factor.

Method and experiment

The transmission factor (T) depends on pressure (P), beam energy (E) and path length (L):

$$T = \exp\left(-2.69 \times 10^{14} \int_0^L \sigma(E) P(x) dx \right) \qquad (1)$$

where P is the pressure in Pa, dx is an element of pathlength in cm and σ is the sum of all the relevant cross sections in cm^2/molecule.

In the case of using an internal ion source, the ion beam energy is constant along the beam path in the puller, thus, the transmission factor depends only on the average pressure (P_{av}). To calculate the transmission factor it was necessary to obtain the pressure distribution inside. The pressure inside the puller (P_{pu}) depends on molecular conductivity, ion source slit's dimension and gas flow rate from the ion source. The gas flow rate is a function of H^- ion beam intensity and arc current of PIG ion source [2]. To simulate the pressure distribution in the puller (P_{pu}) a model of an ion source and a puller has been manufactured as shown in figure 1.

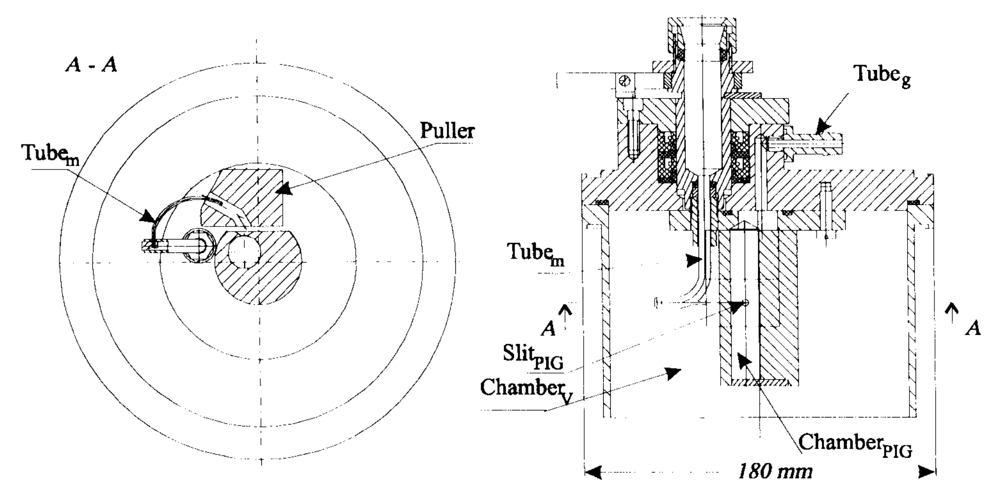

Figure 1. Experimental model of a cyclotron central region with "closed" puller.

This model consists of two chambers. One of them represents the PIG ion source ($chamber_{pig}$). This chamber is connected to a gas reservoir through a gas controller valve. The gas flow coming in the gas source chamber is getting out through the hole that represents slit ($slit_{pig}$) of the ion source. The second chamber represents the vacuum chamber ($chamber_v$) that includes the puller. During the measurements the cyclotron's central region has been simulated using three different geometrical configuration:

1) puller is a bent hole 6 mm in diameter and 22 mm in length in a metallic piece ("closed" puller);

2) the previous closed puller was replaced by a vertical plate 1.5 mm in thickness that has a hole 6 mm in diameter as a puller ("open" puller), see figure 2;

3) two horizontal plates located at a distance of 15 mm from each other were fixed on the previously described vertical plate (open puller + dee), figure 3.

The pressure was measured in three places. The first place was located between the controller valve and the gas source chamber ($chamber_{pig}$) and the pressure measurement was provided by the Pirani gauge PMT6-3M. The second measurement was done in the vacuum chamber ($chamber_v$) by means of the Penning gauge PMM32. The third measurement gave us the pressure distribution in the puller. The pressure distribution was determined by means of a tube ($tube_m$) with 1 mm diameter that moves step by step through the puller by the curvature belonging to the trajectory of ions. This tube is connected to the vacuum measurement device (Pirani gauge PMT6-3M).

The measurements under the above conditions were carried out with two $slit_{pig}$ diameters (3.4 mm and 1.7 mm) in order to investigate the $slit_{pig}$'s area effect on the P_{pu}. The gas flow rate coming out from the ion source was varied up to 17 standard cm^3/minute (sccm). The experimental results are presented in table 1.

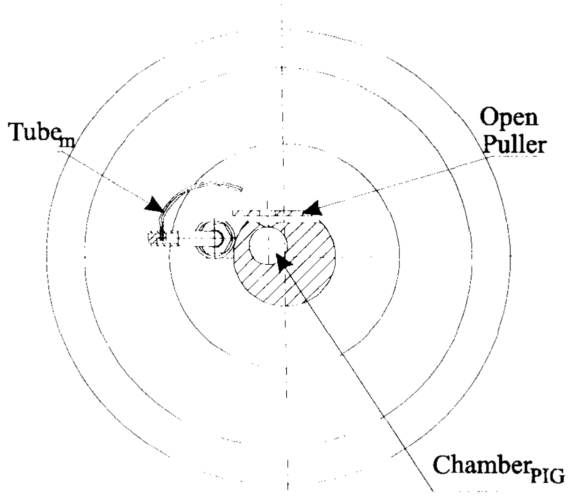

Figure 2. Experimental model of a cyclotron central region with "open" puller.

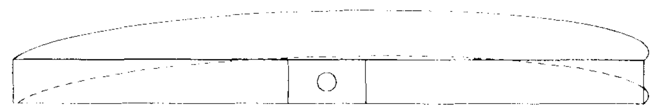

Figure 3. Scheme of Open puller + Dee.

The example of the pressure distributions for $slit_{pig}$ diameter of 3.4 mm is shown in figure 4. For estimation of the transmission factor along 22 mm beam trajectory, the charge exchange cross section for H^- ion in H_2 as a residual gas was accepted equal to $9.1 \cdot 10^{-16}$ and $8.7 \cdot 10^{-16}$ cm^2/molecule for the voltage 15 and 20 kV on the puller respectively [3,4]. The existence of the horizontal plates that represent cyclotron's dee, has not a significant influence on the pressure raising. Figures 5 and 6 show the transmission factor versus the average pressure for the cases presented in table 1.

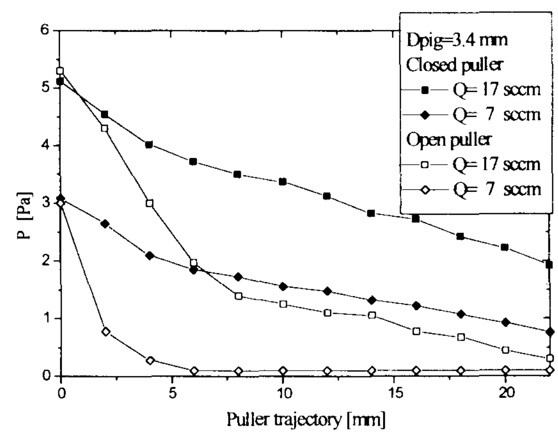

Figure 4. Pressure distributions for $slit_{pig}$ diameter of 3.4 mm

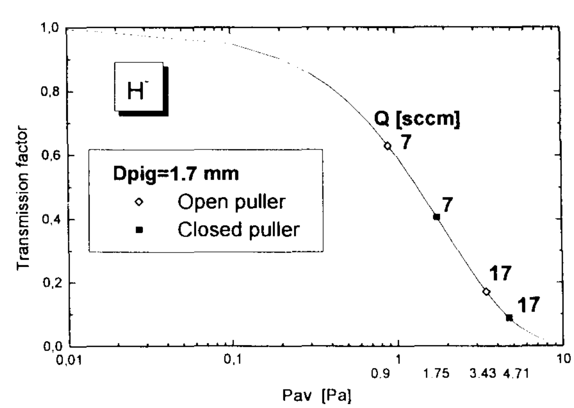

Figure 5. Transmission factor versus average pressure for $slit_{pig}$ diameter of 1.7 mm.

Table 1. Conditions and results of experiments.

Conditions of experiments	Q [sccm]	P_average [Pa]	Transmission factor for U_{DEE} = 20 kV	Transmission factor for U_{DEE} = 15 kV
Diameter of $Slit_{PIG}$ D_{PIG} =3.4 mm				
Puller Dpu=6 mm	1	0.1	0.95	0.945
	2.3	0.36	0.83	0.82
	4	0.86	0.64	0.63
	4.8	1.1	0.57	0.55
	7	1.6	0.43	0.42
	17	3.3	0.18	0.17
Open puller Dpu=6 mm Without Dee	7	0.27	0.87	0.86
	17	1.7	0.41	0.40
Open puller + Dee	7	0.3	0.86	0.85
	17	1.75	0.41	0.39
Diameter of $Slit_{PIG}$ D_{PIG} =1.7 mm				
Puller Dpu=6 mm	7	1.75	0.4	0.39
	12.8	4.7	0.09	0.08
Open puller Dpu=6 mm Without Dee	7	0.9	0.65	0.64
	12.8	3.4	0.17	0.16

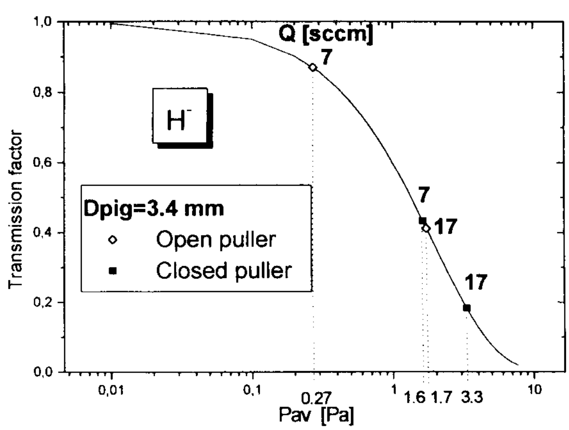

Figure 6. Transmission factor versus average pressure for $slit_{pig}$ diameter of 3.4 mm.

Conclusion

As the described measurements demonstrate, there is a significant difference between two geometrical configurations:

1) closed (long and bent) puller;
2) open (short) puller

in pressure distribution and consequently in the transmission factor.

In the case of the open puller, the transmission factor is twice as large as that for the closed one. Therefore, it is necessary to take into account the beam loss due to charge exchange along the beam trajectory in the puller and to optimise the geometrical configuration of the central region from the point of view of conductivity and pumping efficiency.

References

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