Some Aspects of Construction of ECR Ion Source Vacuum Systems

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Abstract

A view on some aspects of construction of the ECR ion source vacuum systems is given. Scaling relationships are presented as a basis for understanding the vacuum configurations of the ECR ion sources. Typical, total specific outgassing rates for some materials together with mass spectra of 'O' rings (PERBUNAN - N, VITON) used in construction of the DECRIS ion source and background of the tested chamber are shown.

1. INTRODUCTION

In the design and selection of suitable pumping systems for use in the ECR ion source constructions scaling relationships and outgassing characteristics of materials exposed to vacuum are very important. The scaling relationships allow us to determine the pressure profile along the beam pipe, the maximum pressure between pumps and conductances for different flows. The outgassing data are obviously based upon the throughtput measurements controlled by monopole (quadrupole) or other residual gas spectrometers. A variety of materials have been tested at room temperature. Test results are presented for materials as teflon, viton, currently used 'O' ring (Perbunan - N from Roumania) at our laboratory, textile glue epoxy resin (textolit - textit), and steel samples.

2. SCALING RELATIONSHIPS

The highest obtainable average pumping speed of the ECR ion source vacuum system strongly depends on the beam pump conductance. To illustrate this important limitation caused by the finite conductance, let us consider the system shown in Figure 1. In the molecular flow regime the flow of molecules along the vacuum pipe to the nearest pump is expressed by the equation

$$Q(x) = -w\frac{dp}{dx} \qquad \frac{dQ}{dx} = Aq \tag{1}$$

where Q is the gas flow (Pa m^3 s^{-1}), w is the specific molecular conductance (m^4 s^{-1}) (w = LC), C is the conductivity (m^3 s^{-1}), p is the pressure inside the pipe (Pa), A is the specific surface area (m) (A = F/L), F is the surface area (m^2) and q is the specific outgassing rate (uniform) (Pa m s^{-1}). These equations can be combined to give

$$w\frac{d^2p}{dx^2} = -Aq \tag{2}$$

together with the boundary conditions of this simple problem

$$\left.\frac{dp}{dx}\right|_{x=L/2} = 0 \qquad \text{and} \qquad p|_{x=0} = \frac{AqL}{S} \tag{3}$$

which follow from evident symmetry considerations. As the solution we can find a well known parabolic pressure profile along the beam pipe

$$p(x) = Aq\left(\frac{Lx - x^2}{2w} + \frac{L}{S}\right). \tag{4}$$

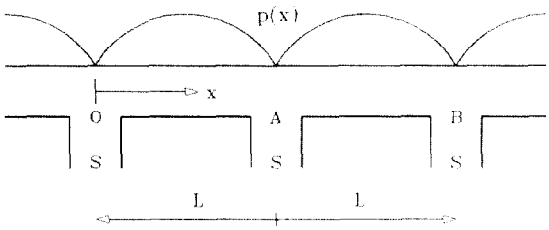

Figure 1. Outline of the ECR pumping system. S is the pumping speed of the pump in points "O", "A", "B" (m^3 s^{-1}), L is the distance between pumps (m) and x is the distance measured from the reference point "O" (m).

The maximum pressure occurs at the midpoint between pumps

$$p_{max} = Aq\left(\frac{L^2}{8w} + \frac{L}{S}\right). \tag{5}$$

For the ion source pipe the average pressure is more relevant

$$p_{av} = \frac{1}{L}\int_0^L p(x)dx = Aq\left(\frac{L^2}{12w} + \frac{L}{S}\right). \tag{6}$$

It is convenient to define an "effective linear pumping speed"

$$S_{eff} = \left(\frac{L^2}{12w} + \frac{L}{S}\right)^{-1} \tag{7}$$

so that $p_{av} = Aq/S_{eff}$. It is evident that S_{eff} cannot exceed $12w/L^2$ irrespective of how large pumps are used.

Equally, the lowest achievable average pressure is limited to $AqL^2/12w$. Since the conductance is generally

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determined by the appertures in electrodes and screens (screening of the high frequency), the only parameter is the interpump distance L. Obviously, many small pumps at short distance are preferable to a few and large pumps. It is shown[1] that the effective pumping speed is practically the 'linear' function of the pump distance for various sizes of pumps. Such a pumping structure may be installed along the vacuum system and hence the analysis provides a 'linear pumping speed' inside the beam pipe.

The real pressure distribution and therefore the average pressure also follow from the equation similar to the previous one

$$-w\frac{d^2p}{dx^2} = Aq - sp \tag{8}$$

where s is the specific pumping speed defined as $s = S/L$ ($m^2\ s^{-1}$). By the solution of differential equation (8) using the boundary conditions (3) we find other pressure profiles along the beam pipe. It holds that

$$p(x) = C_1e^{rx} + C_2e^{-rx} + \frac{Aq}{s} \tag{9}$$

where

$$C_1 = \frac{AqL}{S}e^{-rL}(1+e^{-rL})^{-1}, \qquad r = (s/w)^{0.5}$$

and

$$C_2 = \frac{AqL}{S}(1+e^{-rL})^{-1}.$$

Usually, the vacuum system is designed with respect to s≪w. In this configuration one can obtain

$$C_1 \cong C_2 \cong C_o = \frac{Aq}{2}\frac{L}{S}. \tag{10}$$

The equation (9) is reduced to

$$p(x) = C_o(e^{rx} + e^{-rx}) + \frac{Aq}{s} \tag{11}$$

and the average pressure is determined by

$$p_{av} = \frac{C_o}{rL}(e^{rL} - e^{-rL}) + \frac{Aq}{s} \cong \frac{2AqL}{S}. \tag{12}$$

It is evident that the lowest achievable pressure depends only on the ratio of 2AqL/S. The average pressure versus the distance between pumps L for different pumping speeds S (0.02, 0.04, 0.06, 0.12, 0.24, 0.5 and ∞ $m^3\ s^{-1}$) is shown in paper[1].

3. RESIDUAL GAS SPIECES RESULTS

Outgassing characteristics of several materials were studied in vacuum at room temperature for periods as long as 48 h. Samples were placed in a stainless steel vacuum chamber which was evacuated by a 0.5 $m^3\ s^{-1}$ turbomolecular pump. The vacuum chamber volume and surface area were approximately 0.0025 m^3 and 0.12 m^2, respectively. Pressures were measured from 0.1 MPa to 10^{-6} Pa by using a combination of thermocouple, Pirani, Bayard -Alpert and Penning gauges.

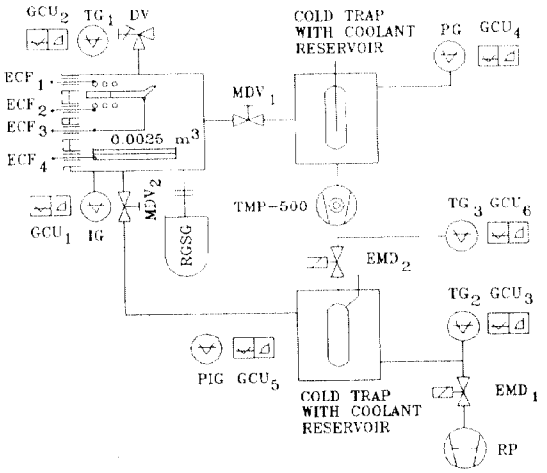

Figure 2. Scheme of the stand use for measuring of the RGA spectra. RP is rotary pump, TMP is turbomolecular pump, ECF is electrical current feedthrough, DV is dosing valve, RGSG is residual gas spectrometer gauge, MDV is manual drive valve, EMD is electro - magnetic drive valve, PG is Penning gauge, IG is ionization gauge, TG is thermocouple gauge, PIG is Pirani gauge, and GCU is gauge control unit.

Typically, the test chamber and connecting lines were conditioned between test runs using a vacuum bakeout at about 150 °C at a base pressure of about 10^{-4} Pa. Concurrently, the RGA (Residual Gas Analyser) probe was baked out at 150 °C. A minimum of 10 h was allowed for the chamber to cool to room temperature prior to loading the next test samples.

The residual gases which were evolved from the samples under test were determined using the zero order method of peak height summation and by subtracting the spectra measured of the empty test chamber from the spectra measured with the samples.

3.1. Vacuum stand

Scheme of the stand is shown in Figure 2. It is designed to pump the vacuum chamber with diagnostic elements and gauges to the pressure of 10^{-6} Pa. The entire system including the holder of the samples is constructed of stainless steel, combined with copper and steel materials, respectively. One rotary pump is used in order to produce the vorvacuum (BL 90).

The rotary and turbomolecular pumps continuously pump the whole system. The rotary pump is also used for slow - acting evacuation of the tested chamber before connection of the turbomolecular pump.

Proceeding from the dimension of the vacuum system an effective speed S_{eff} is calculated for the center of the stand chamber. There was found to be: $S^{ch}_{eff} = 0.1$ m^3 s^{-1} for air at 10^{-5} Pa. The reduced pumping speed of the turbomolecular pump is mainly due to the small diameter of the used pipes and trap, respectively.

Table 1. Specific outgassing rates q for some materials used in our vacuum technology; PERBUNAN - N is produced in Roumania and other ones are produced in Russia.

Sample	Exposure (h)	Pressure (Pa)	q (Pa m s^{-1})
STEEL "3"	24	8 x 10^{-5}	3.6 x 10^{-6}
TEFLON	20	3.5 x 10^{-6}	2 x 10^{-4}
TEXTOLIT - TEXTIT	20	3.5 x 10^{-5}	1 x 10^{-3}
EPOXY	48	4 x 10^{-6}	8 x 10^{-6}
'O' RING - PERBUNAN -N	24	2.5 x 10^{-4}	2 x 10^{-3}
'O' RING - VITON	24	7 x 10^{-6}	6.5 x 10^{-5}

3.2. *Results*

The specific outgassing rates are summarized in Table 1. It is seen that the VITON 'O' ring is better than PERBUNAN-N by a factor of 40 times and TEFLON is worse than STEEL by a factor of 50 times. The worst materials are the PERBUNAN-N, TEXTIT and TEFLON.

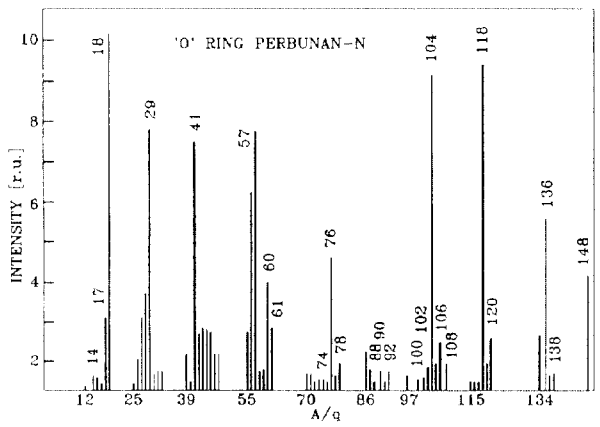

Figure 3. Spectrum of 'O' RING PERBUNAN -N from the plasma of the RGA spectrometer MX 7304 (monopole).

The outgassing rates presented for the VITON are the same than those reported in[2]. Similarly, our results again indicate not to recommend the use of the PERBUNAN-N, TEFLON and TEXTIT for clean interior surfaces of the ECR ion source vacuum systems.

Some of the RGA spectra are shown in Figures 3 - 4. The spectra are measured by the RGA spectrometers MX 7304 (monopole) and IPDO - 2A (omegatron), respectively. The spectrometer gauges are placed directly on the measuring chamber of the stand (Figure 2). By spectra analysis one can see the peak sets as 27, 29; 39, 41, 43; 55, 57, 58; 69; 77, 78; 85, 87; 101, 103, 105; 130, 132, 134, 136; 149, 151, 153, 155; 198; corresponding to the characteristic clusters of the n - C_x H_y hydrocarbons, or m - C_r Cl_w F_z freons. These fragments arise also during the ionization processes from oils used in the backing pumps, some diffusion pumps and turbomolecular pumps.

In addition to the spectra the expressive water vapor contamination is illustrated but there are also the peaks as 135, 137, 138, 140, 148 and 220 which can give rise to some difficulties in interpretation, mainly if the vacuum chamber is made of the stainless steel and if it is devided from the vacuum pumps by two liquid nitrogen traps. Nevertheless, by means of the spectral catalogs, where the spectra of the pure substances are standardized, it is possible to find the appropriate substances in the majority of cases.

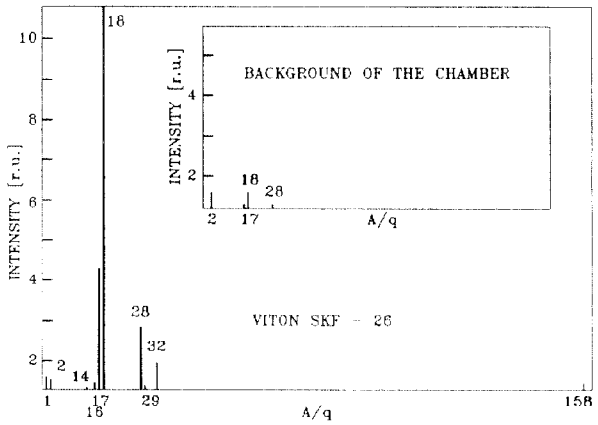

Figure 4. Spectrum of 'O' RING VITON and background of the chamber from the plasma of the RGA spectrometer MX 7304 (monopole).

4. CONCLUSION

The present work describes not only the scaling relationships used for the construction of the vacuum systems of the ECR ion sources but also provides the new data in the region of the outgassing rates and the RGA spectra for the different solid materials. Taken together, all these data show that it may be impossible to obtain the suitable operation vacuum (10^{-5} Pa) and the necessary cleanliness of the ion source and the beam lines if the vacuum exposed surfaces have higher specific outgassing rates than 10^{-4} Pa m s^{-1}.

5. REFERENCES

[1] J. Pivarč, "Main Features of the ECR Ion Source Vacuum Systems", JINR Report E9-93-332, Dubna, Russia, October 1993, pp. 1 -16.

[2] R.D. Craig, "Degassing Characteristics of Some 'O' Ring Materials", Vacuum, vol.-20, pp. 139-142 January, 1964.