Vacuum Instability in the SIS18

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The so-called "loss induced" vacuum degradation was observed at LEAR (CERN), the AGS Booster and RHIC at Brookhaven, and the SIS18 at GSI [1]. In this kind of instability a large gas desorption ($\eta \approx 10^4 - 10^6$) from the vacuum chamber wall is produced by the lost high energy beam ions.

We propose a theoretical modelling and apply it to the U^{+28} beam lifetime measurements at SIS18. The evolution of the vacuum pressure $P(t)$, averaged along the accelerator, can be described by the following equation:

$$\frac{dP}{dt} = -\frac{1}{\tau_p}(P - P_e) + \frac{L}{VeZ_p}\eta\sigma IP, \quad (1)$$

where e is the elementary charge, Z_p is the charge state of the beam ions, L is the length of the orbit, I is the beam current, τ_p is the total pumping time, P_e is the average static pressure, η is the desorption yield coefficient, σ is the cross-section of charge-exchange of the beam ions. The condition of vacuum pressure stability derived from Eq.(1) is:

$$I < \frac{VeZ_p}{L\tau_p\eta\sigma}. \quad (2)$$

The ion beam current I in Eq. (1) cannot be considered to be constant, and its evolution with time is given by the equation of lifetime:

$$\frac{d}{dt}\ln\left(\frac{I}{I_0}\right) = -\sigma\beta c n_L P = -\frac{1}{\tau_{life}}, \quad (3)$$

where βc is the velocity of the beam particles, $n_L \approx 2.7 \cdot 10^{25}$ m^3 is the Loschmidt constant, I_0 is the initial value of the beam current.

If the charge-exchange (stripping or electron capture) of the beam ions due to collisions with molecules of the residual gas is the dominant beam loss mechanism (so the other sources of losses can be neglected), then the system of Eq. (1), Eq.(3) can be used to derive the desorption yield η from the ion beam lifetime measurements, by tuning the τ_p, σ, η and P_0 parameters in order to get the best fit of $I(t)$ calculated by Eq. (1), Eq.(3) to the measured values of the beam current.

The U^{+28} beam was stored at the injection energy of E = 8.9 MeV/u. Varying the injection pulse length we could store beams with different initial current, but also with different initial losses, the latter resulting in different and unknown initial vacuum pressure values P_0. Using as average radius of the vacuum tube r=8.2 cm and $P_e = 5 \cdot 10^{-11}$ mbar the results of the fit are shown in Table 1. For $I_0 = 5.36$ mA the pressure evolution $P(t)$, resulting from the fitting to the measured $I(t)$, is shown in Fig. 1.

The charge-exchange cross-sections, obtained from the fit Table 1, are $4 \div 11$ times larger than those predicted by the theoretical calculations $\sigma_{theor} \approx 0.2 \cdot 10^{-20}$ m^2 [2], which may be due to different residual gas composition or uncertainties in the theory. In general, the spread of values obtained from the fit to the different sets of measurement shows that the overall accuracy of the method is not better than a factor of 2.

Table 1: Fit to the U^{+28} current measurements.

I_0, mA	τ_p, s	σ, m^2	η	P_0, mbar
1.08	0.24	$1.1 \cdot 10^{-20}$	20000	$6.0 \cdot 10^{-11}$
1.40	0.32	$0.8 \cdot 10^{-20}$	27000	$14 \cdot 10^{-11}$
1.97	0.24	$1.3 \cdot 10^{-20}$	16000	$6.5 \cdot 10^{-11}$
5.36	0.26	$2.1 \cdot 10^{-20}$	11000	$10 \cdot 10^{-11}$

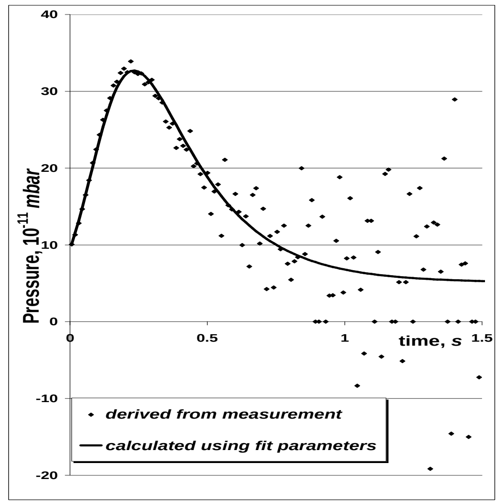

Figure 1: Fitting of the pressure evolution in SIS18 with U^{+28} beam circulating at a constant energy E=8.9 MeV/u

The desorption yield values are of the same order of magnitude like those measured at CERN: $\eta \approx 2 \cdot 10^4$ for Pb^{+53} ions with energy $E = 4.2$ MeV/u [3] hitting the vacuum chamber wall at a grazing incidence of 14 mrad. Fig. 1 shows a clear evidence of a pressure run-away in the SIS18 with a U^{+28} beam of intensity $I = 5$ mA. The growth time of the instability is about 200 ms in this case. Eq. (2) suggests three "knobs" to increase the threshold current: pumping time τ_p, desorption yield η and charge-exchange cross-section σ. A special treatment of the vacuum chamber surface, or use of special materials (like NEG-coated stripes) can decrease the effective desorption yield. In order to investigate the practical efficiency of these measures a test-stand experiment is under preparation at GSI [1]. The charge-exchange cross-sections can be reduced by use of higher charge states of accelerated ions, which raises the question of enhanced space charge problems.

References

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