Experimental Investigation of Impact-Induced Molecular Desorption by 4.2 MeV/u Pb ions

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Abstract

In preparation for the heavy ion program of the LHC [1], accumulation and cooling tests with lead ion beams have been performed in the LEAR storage ring [2]. These tests have revealed that due to the unexpected, large outgassing of the vacuum system, the dynamic pressure of the ring could not be maintained low enough to reach the required beam intensities. To determine the actions necessary to lower the dynamic pressure rise, an experimental program has been initiated for measuring the molecular desorption yields of stainless steel vacuum chambers by the impact of 4.2 MeV/u lead ions with the charge states +27 and +53. The test chambers were exposed either at grazing or at perpendicular incidence. Different surface treatments are reported in terms of the molecular desorption yields for H_2, CH_4, CO and CO_2. Unexpected large values of molecular yields per incident ion up to 1.5×10^4 molecules/ion have been observed. The implications of these results for the vacuum system of the future ion accumulator ring (LEIR) and possible remedies to reduce the vacuum degradation will be discussed.

1 INTRODUCTION

In preparation for the heavy ion program of the LHC [1], accumulation and cooling tests with lead ion beams have been performed in the LEAR storage ring [2]. The static pressure of the LEAR machine was 5×10^{-12} torr, but was observed to rise five-fold during the accumulation tests. This increase in the pressure reduced the lifetime of the circulating beam to only 6.5 s, causing the maximum accumulated intensity to be a factor of two less than desired. Already at this early stage the vacuum was observed in real time, and a clear connection between the instantaneous pressure in the machine and the beam current was observed. These observations lead to the conclusion that the pressure increase was caused by desorption of residual gas molecules adsorbed on the chamber walls by lead ions lost due to charge exchange with the residual gas [3]. This observation is similar to an effect experienced at the AGS Booster [4].

In order to quantify the desorption as well as to find a possible remedy, an experimental study of the molecular desorption yield from lead ion impact on a vacuum chamber surface has been carried out. We present the results from this experiment, and discuss the implications for the vacuum system of the future ion accumulator ring (LEIR).

2 EXPERIMENT

Figure 1 shows an overview of the experimental setup. The lead ions are supplied by the LINAC3 at CERN, which delivers 4.2 MeV/u Pb^{27+} ions. The experiments were carried out both with charge states +27 and +53. To obtain charge state +53 (which is the charge state to be used for accumulation in the future LEIR) the Pb^{27+} beam is sent through a stripping foil (a). The beam is then steered through a magnetic beam optical system which gives control over the beam size and divergence in the test chamber. A dipole magnet separates the different charge states out of the stripping foil, and a simple collimator is used to select the desired charge state.

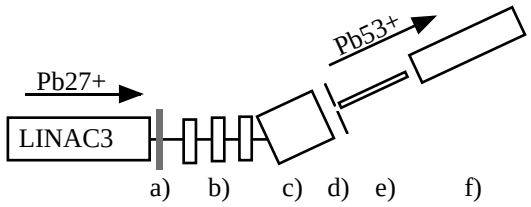

Figure 1: Experimental Setup at LINAC3. a) Stripping foil. b) Optical elements to focus the beam into the experiment. c) Bending magnet to spatially separate charge states. d) Collimator to select only one charge state. e) Thin tube through which the pumping takes place (ø35 mm). f) Test chamber with dimensions 1440 mm × ø145 mm.

In order to measure the desorption rates as well as the nature of the desorbed molecules, an ionization gauge and a residual gas analyzer are connected to the test chamber. After the initial baking and pumping down of the chamber using a turbo molecular pump unit, the whole system is sealed off and the pumping occurs through a long narrow stainless steel pipe (through which the beam also passes), which serves to make the pumping speed independent of the state of the Ti-sublimation and the Ion pump used for pumping.

To measure the desorption rates, the linac can either deliver 560 μs shots of approximately 10^{10} Pb^{27+} ions, yielding 1.5×10^9 Pb^{53+} ions, every 1.2 s or on specific request (single shot). The angle of the test chamber with respect to the beam can be varied, and the chamber can be set such that the beam impacts on the end flange of the chamber rather than at grazing incidence on the side of the chamber. Calculations based on the situation during the accumulation experiments in LEAR show that the minimum expected impact angle of the lead ions to the surface of the chamber is 14 mrad [3].

0-7803-7191-7/01/$10.00

3 RESULTS

For the tests, three different pre-treatments of the vacuum chambers were used.

Chamber **A** : Chamber representing the standard treatment in LEAR. The chamber was exposed to the CERN standard cleaning procedure (CERN/PS.TR01) and vacuum fired at 950°C. After installation, the chamber was baked at 300°C for 24 hours.

Chamber **B** : Cleaning and vacuum firing like chamber A. Next, 24 hours of baking at 300°C. Then, the chamber was exposed to Ar-O_2 glow discharge cleaning[1] with 0.8A for 1.5 hours at 300°C, and baked at 350°C for 24 hours to remove the Ar from the surface [5]. The chamber was vented with N_2 before installation in the test stand. After installation, the chamber was baked to 350°C for 24 hours.

Chamber **C** : After an initial cleaning and vacuum firing like chamber A the chamber was coated with a Non-Evaporable Getter (NEG) of Ti-Zr-V. After installation, the chamber was baked at 100°C for 36 hours during which the rest of the system was baked at 300°C. Next, the temperature was increased by 20°C/h to 200°C and left at 200°C for 24 hours in order to activate the NEG coating.

Figure 2 shows the total pressure in chamber A over a period of about four hours during which is was exposed first to a series of single shots of Pb^{53+}, and then to a period of shots every 1.2 s.

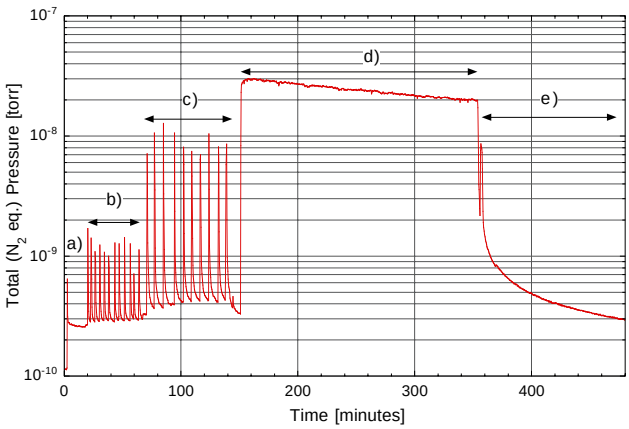

Figure 2: Pressure in the chamber A during a period in the experiment. The particles impacted with 14 mrad grazing incidence. a) Sector valve separating the experimental line from the LINAC3 is opened. b) A series of single shots of 1.5×10^9 Pb^{53+} ions. The shot interval is given by the time needed for the vacuum to return to the conditions before each shot. c) A series of single shots of 10^{10} Pb^{27+} ions. d) Pb^{53+} shots with a repetition rate of 1.2 s. e) Beam switched off. Sector valve closed.

[1]The gas mixture was 10% O_2 and 90% Ar

From the measurement in Figure 2 one finds that the loss of about 1.3×10^9 Pb^{53+} ions/s cause a pressure increase of a factor 91. With the calculated pumping speed of 26.8 L/s (for H_2) this equals a desorption yield η of 1.5×10^4 molecules per Pb^{53+} ion. This large desorption yield strongly supports the hypothesis that the reported pressure increase in LEAR of a factor 5 is due to lost lead ions. It has been calculated that the lost ions impact mainly with grazing incidence (14 mrad at the extreme) [3]. However, theory indicates that less grazing incidence (or even perpendicular) gives smaller desorption yields. Measurements of the yield with 90 mrad grazing incidence, and perpendicular incidence, were therefore also carried out.

The cleaning effect evident in Figure 2 during the repeated shots was not observed during the LEAR experiments. However, the intensity per unit area on the surface in LEAR was about a factor 100 smaller, thus careful investigations would have been necessary to observe the effect.

Measurements similar to the one shown in Figure 2 were carried out on all three chambers and with perpendicular, as well as grazing incidence. The pressure rises under continuous shot exposure are summarized in Table 1

	Perpendicular	90 mrad	14 mrad
A	3.7×10^{-9} torr ($\times$15)	1.3×10^{-8} torr ($\times$42)	2.9×10^{-8} torr ($\times$91)
B	1.3×10^{-8} torr ($\times$33)	4.3×10^{-8} torr ($\times$109)	1.5×10^{-7} torr ($\times$333)
C	4.0×10^{-10} torr ($\times$5)	4.0×10^{-10} torr ($\times$5)	1.3×10^{-9} torr ($\times$16)

Table 1: Absolute and relative pressure rises (in brackets) in the test chambers when exposed constantly to shots of 1.5×10^9 Pb^{53+} ions every 1.2 s for three different chambers and three different incidence angles.

The results shown in Table 1 confirm the earlier assumption that grazing incidence of 14 mrad desorbs the most molecules from the surface. It is also observed, as expected, that the pressure in the NEG coated chamber is significantly lower that in the other chambers. One surprise however is that the Ar-O_2 glow discharged chamber B is not better than chamber A; significantly larger pressures are observed in chamber B.

In order to better evaluate these results and compare the different chambers, information is needed about the residual gas distribution. To be able correctly to evaluate the desorption rates from the equilibrium partial pressures, the pumping speeds are necessary, which can be measured by measuring the equilibrium pressure with a controlled inflow. As a supplement to this method and in order to learn more about the dynamics of the desorption, another approach was also applied. In this approach the partial pressure development of each component that is desorbed due to a single shot is measured. The desorption yield is then given by the maximum observed partial pressure, assuming

that the pumping is significantly slower that the desorption process. Figure 3 shows an example of the partial pressures of CO after a shot of 1.5×10^9 Pb^{53+} ions. These measurements were done with the residual gas analyzer set to monitor one specific mass at a time; in this way the time development of the partial pressures of several important residual gas components was studied.

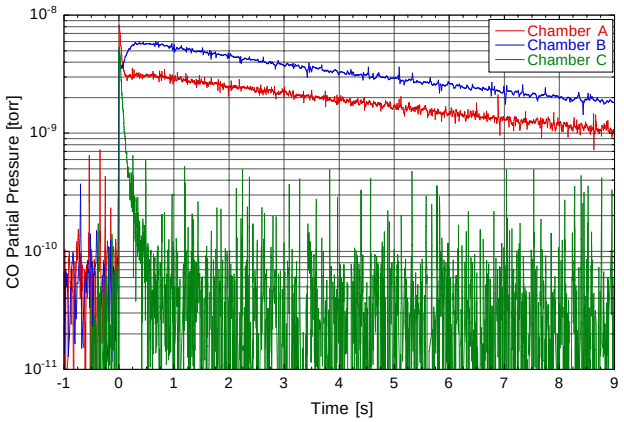

Figure 3: Partial pressure of CO versus time when the three chambers are exposed to a single shot of 1.5×10^9 Pb^{53+} ions at 14 mrad grazing incidence.

Figure 3 shows clearly the significantly increased pumping speed of the NEG coated chamber C. Furthermore it is observed that the amount of released gas, expressed in terms of the peak partial pressure, is lower for chamber C than for the others, and that chamber B releases a factor two more gas than A. However, the very narrow peak in the pressure for chambers A and B right after injection indicate the actual release of B is lower (as expected) but that the sticking factor (the rate of molecules getting readsorbed on the surface) is larger for chamber A, and thus that the actual gas release is higher.

From the measurements in Figure 3 it was found that an important fraction of the gas released due to impact of lead ions is CO. As the heavier components of the residual gas influence the lifetime of a circulating beam more, all the major molecular species released during an impact were studied in the same fashion. Figure 4 shows a comparison of the number of molecules released per incident Pb^{53+} ion of different molecular species for the three chambers.

Figure 4 shows that the desorption yields only vary slightly with the chamber type apart from Ar of which significant amounts are released from chamber B. Furthermore the total desorption yield found with this method is about 10^4, in agreement with the yield found from the equilibrium measurement.

4 CONCLUSIONS

We have studied the molecular desorption yield of various residual gas components from the stainless steel surface of a vacuum chamber due to impact of 4.2 MeV/u lead ions

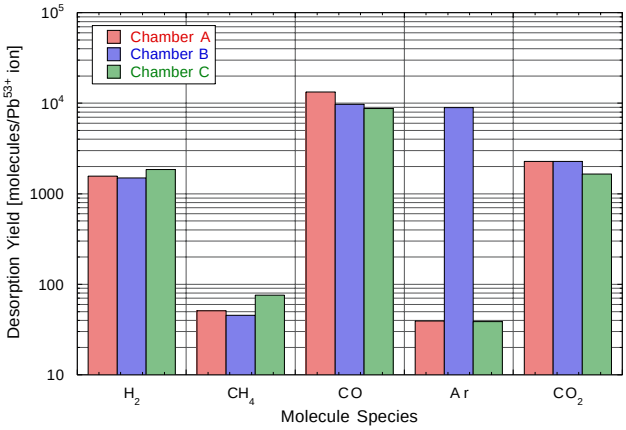

Figure 4: Desorption yields measured with single shots of 1.5×10^9 Pb^{53+} ions at 14 mrad grazing incidence.

for three different surface treatments under grazing and perpendicular incidence of the ions.

Two overall conclusions may be drawn from the investigations. Firstly, strong evidence that the pressure rise observed in LEAR during lead accumulation tests is indeed due to loss of charge-exchanged lead ions impacting on the inner surface of the LEAR vacuum chamber, has been observed. It was found that each lost lead ion desorbed about 10^4 molecules. Secondly we have found that neither Ar-O_2 glow discharge nor a NEG coating reduce the desorption yields. In fact the experimental results show an increased desorption yield for the Ar-O_2 glow discharged chamber. In particular the desorption yield of Ar was 200 times larger for the Ar-O_2 glow discharged chamber than for the other two. However it was also observed that the angle of incidence has a significant influence on the desorption yield, grazing incidence leading to the highest yields.

As a consequence of these results, the remedy for improving the dynamic pressure in the future ion accumulator for the LHC (LEIR) seems to be to make changes to the vacuum chamber such that the ions lost are mostly lost at perpendicular incidence. The desorption yield at these specific points may further be reduced by pretreatment with lead ion bombardment. This is a feasible solution as it has earlier been found that the main part of the ions lost, are lost in the bending magnets of the machine [3].

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