VACUUM SIMULATIONS FOR HEAVY ION BEAMS IN THE AGOR CYCLOTRON*

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Abstract

The TRIμP program at the KVI requires the development of high intensity heavy ion beams in particular $^{206}Pb^{27+}$ at 8.5 MeV/amu and $^{20}Ne^{6+}$ at 23.3 MeV/amu. For the Pb beam, losses in the cyclotron are one of the factors limiting the intensity that can be achieved. Charge changing collisions between the heavy ion beam and the residual gas cause subsequent desorption off the walls of the cyclotron which in turn leads to vacuum degradation. This causes a positive feedback loop leading to a reduced transmission with increasing beam intensity. We have developed a model to track the trajectory of the particles after a charge changing collision and 3D vacuum simulations to predict pressure profiles from desorption values. We have built and tested an experimental setup to measure beam induced desorption for relevant materials. Preliminary results are described.

INTRODUCTION

The TRIμP program at the KVI requires high intensity Pb beams for which transmission is to be maximized because of the limited intensity from the ion source. Primary beam loss in the cyclotron occurs when collisions of beam particles with the residual gas, mostly H_2O and N_2, lead to a change in the charge state of the ion. The cross-sections for the charge changing collisions depend on ion species and energy (Fig 1).

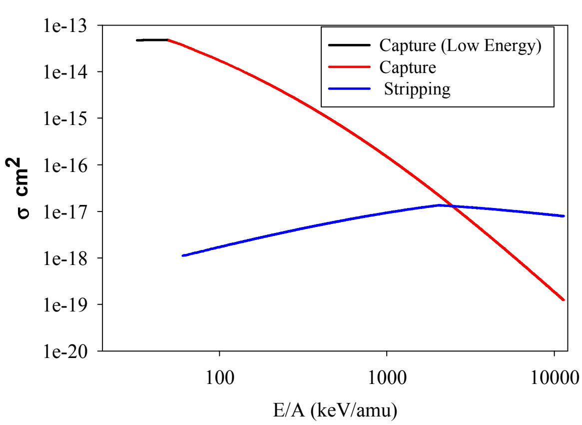

Figure1: Dependence of cross-section of capture and stripping processes on energy [1] [2] [3]

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Using these cross-sections we predicted the transmission for a beam inside the AGOR cyclotron and the injection line for uniform pressure [4]. To study the effect of particles lost through charge exchange on the pressure, we simulated particle tracks after a charge changing collision. From there we calculated the angle of incidence of these particles when they hit the walls of the cyclotron causing desorption. The desorption is dependent on the energy of the particles, their angle of incidence on the wall, as well as the wall material. Desorption leads to a pressure increase and a different pressure distribution. This leads to increased beam loss creating a positive feedback loop.

We are developing a geometrical model to predict the pressure distribution for an arbitrary fixed value of desorption and outgassing. This will be used for further beam transmission calculations.

PARTICLE TRACK SIMULATION

The magnetic field used in the particle track simulation has a sinusoidal flutter term in addition to average magnetic field. This is a simplification of the actual field for a heavy ion in the AGOR cyclotron and has been used as a test case.

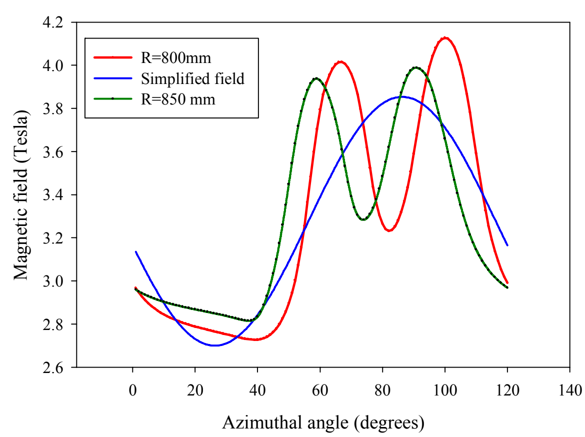

Figure 2: Dependence of the Magnetic field with azimuthal angle, showing actual field at a radius and simplified field as used in simulation.

The equations of motion [5] were solved using the RK4 method of integration for a fixed energy. From a calculated closed orbit, a charge change was simulated and subsequently the particles were tracked.

For a $^{206}Pb^{27+}$ ion, a charge changing collision gives a 4% change in the radius of curvature. Calculations show that the particle then moves in an off-centre orbit close to the original orbit. The particles lost in the central region of the cyclotron do not contribute significantly to the hits on the outer boundary (defined as r =890 mm).

The main contribution to the desorption stems from the high energy particles near extraction (R >870mm), where also the orbit density is highest. Tracking these particles in our simplified preliminary model show that most hit the outer wall of the cyclotron at a grazing angle of incidence, below 8° (Fig 3).

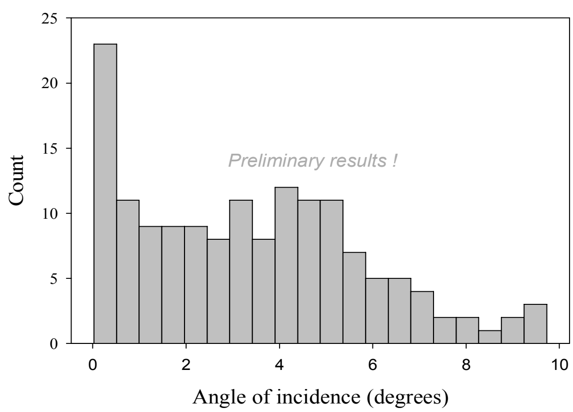

Figure 3: Calculated angle of incidence for particles hitting the walls of the cyclotron with initial radius greater than 870mm.

VACUUM SIMULATIONS

In earlier work we achieved good agreement between calculation and measurements of transmission in the injection line assuming a constant pressure [4]. For the interior of the cyclotron the agreement is not good, probably due to the assumption of a constant pressure profile inside the cyclotron. We developed a model with a simplified geometry to predict the pressure profile gradient for a given outgassing on all surfaces. The geometry is defined in STL format and the simulations are done using MOLFLOW [6]. For simplicity we have replaced the 3 hills and 3 valleys by a hexagon.

Figure 4 shows the density of hits on the top surface of the model. Three of the side walls of the extraction elements have a higher outgassing term to simulate beam loss induced desorption. The central projection (injection area) and other six holes act as the pumping units. The remainder of the walls have a fixed outgassing term. The pumping areas are simulated by areas with unity sticking factor.

The pumping speed is limited by the surface area in MOLFLOW. We are working on a more realistic modelling of the cyclotron vacuum chamber to determine effect of desorption on the pressure distribution in more detail.

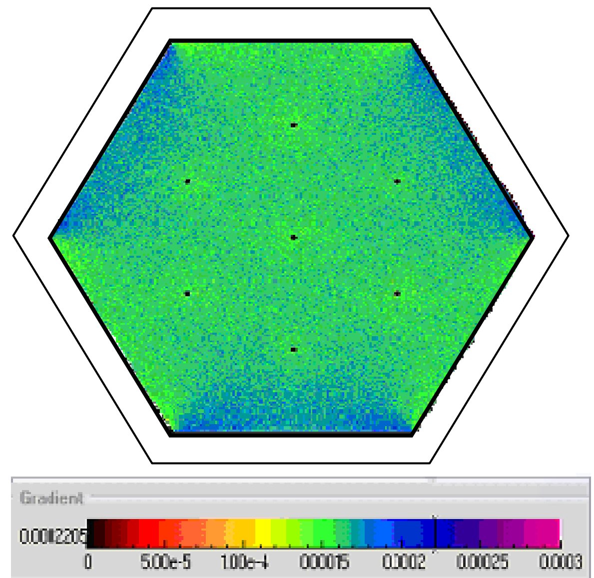

Figure 4: Output from a MOLFLOW simulation.

EXPERIMENT TO STUDY DESORPTION

The beamloss is increased by the vacuum degradation caused by desorption. The particle track simulation shows that the lost particles hit the walls at grazing angles. We therefore set up an experiment to determine the value of desorption for grazing angle of incidence for various beam energies and surfaces.

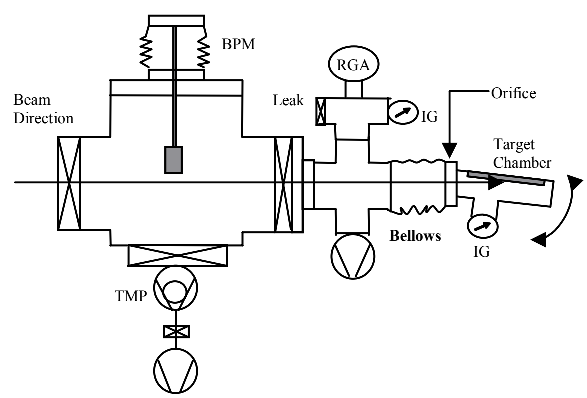

Figure 5: Experimental setup to measure desorption

The setup as shown in Figure 5 has been modified from the setup used by Mahner *et al.* in their desorption experiments [7]. The setup is attached to the AGOR high energy beam line. The target chamber is being differentially pumped by a turbo molecular pump unit of 150 l/s. The pumping speed of the test chamber is conductance limited by the shape of the orifice connecting the test chamber to the bellows. Pressure measurements are made by two ionization gauges (IG) and a quadrupole mass analyzer (RGA). In the main vacuum chamber is a ZnS beam position monitor viewed by a camera, to align the ion beam to the target chamber. The lid of the target chamber acts as the target surface. It is detachable and can be replaced with a different material. The entire test chamber is welded at an angle of 4° to the flange attached to the bellows. Rotating the target changes the angle of incidence of the beam from 1° to 8°.

A first commissioning experiment of the setup has been performed with a $^{20}Ne^{6+}$ beam at 23.3 MeV per nucleon, which is a standard heavy ion beam used for the TRIμP experiments. The target surface was aluminium with no surface treatment. The angle of incidence was fixed at 4°. Beam current was varied from 12 nA to 890 nA. The base pressure in the target chamber was around 5×10^{-6} mbar. For the lower beam currents no rise in pressure above the base pressure was observed. However above 200 nA a measurable pressure increase inside the test chamber occurred. Figure 6 shows the response of the pressure to the intensity of the beam impinging on the target material.

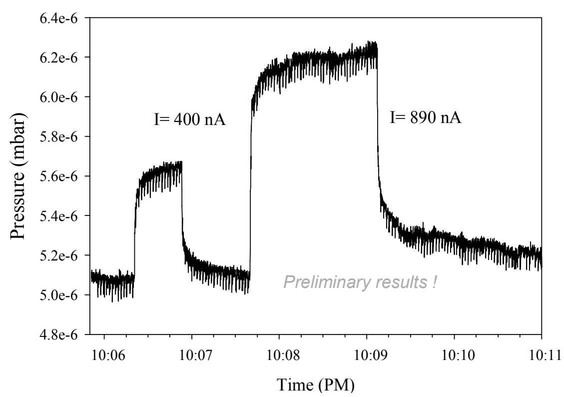

Figure 6: Pressure in test chamber for different beam intensities.

Beam induced desorption is not significant for the neon beam in the AGOR cyclotron. We used the beam for an initial proof of principle on the experimental setup. To measure desorption at lower beam currents a lower base pressure inside the test chamber is needed, which will be achieved by baking.

Further experiments are being designed with the standard $^{206}Pb^{27+}$ beam which does affect the vacuum in AGOR. We will also use different surfaces and surface treatments for a comparative study on desorption. We will in particular study the effectiveness of gold coating which has been shown to effectively reduce desorption [8].

OUTLOOK

The particle tracking simulation gives us the angle of incidence and energy of particles hitting the walls of the cyclotron. The desorption experiment aims to quantify desorption for different beams and surfaces. We will proceed with different surfaces and surface treatments to look for the desorption coefficient at grazing angles. This will be used as input for desorption in the vacuum simulation model to get desorption induced pressure profile inside the cyclotron. The pressure profile will be then used in the particle tracking model with the relevant cross sections to find out the number of particles being lost in charge changing collisions. The entire procedure is iterated till the pressure profile reaches equilibrium. Using the equilibrium pressure profile the final transmission of the beam can be calculated. These calculations will be used to predict and test results of the mitigation measures being implemented in the AGOR like gold plating of the interior of the cyclotron and implementation of scrapers.

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