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BEAM LOSS SIMULATION AND GAS DESORPTION MEASUREMENT FOR HIAF*

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Abstract

Large dynamic vacuum pressure rises of orders of magnitude which caused by the lost heavy ions can seriously limit the ion intensity and beam lifetime of the intermediate charge state heavy ion accelerator. The High Intensity heavy ion Accelerator Facility (HIAF) which will be built by the IMP will accumulate the intermediate charge state ion $^{238}U^{35+}$ to intensity 3×10^{10} ppp to different terminals for nuclear physics, nuclear astrophysics and so on. In order to control the dynamic vacuum effects induced by the lose beams and design the collimation system for the BRing of the HIAF, a newly developed dynamic vacuum simulation program is conducted to optimize the collimation efficiency. Furthermore, two dedicated desorption measurement setups have been established at the terminal of the CSRm and 320 kV HV platform to study the molecular desorption process and do the benchmarking of the simulation code. This presentation will describe the collimation efficiency optimization, measurement results with Sn beam at the CSRm and withthe Xe beam in the HV platform.

INTRODUCTION

The HIAF project consists of ion sources, Linac accelerator, synchrotrons and several experimental terminals. The Superconducting Electron-Cyclotron-Resonance ion source (SECR) is used to provide highly charged ion beams, and the Lanzhou Intense Proton Source (LIPS) is used to provide H_2^+ beam. The superconducting ion Linac accelerator (iLinac) is designed to accelerate ions with the charge-mass ratio Z/A=1/7 (e.g. $^{238}U^{35+}$) to the energy of 17 MeV/u. Ions provided by iLinac will be cooled, accumulated and accelerated to the required intensity and energy (up to 3×10^{10} and 800 MeV/u of $^{238}U^{35+}$) in the Booster Ring (BRing), then fast extracted and transferred either to the external targets or the Spectrometer Ring (SRing) [1].

The intermediate charge state $^{238}U^{35+}$ has been chosen as the reference ion for the facility HIAF. Intermediate charge state particles are much easier lost when they collide with the rest gas atoms and change to other charge states. The resulting change in the mass over charge ratio m/q leads to modified trajectories in dispersive beam transport elements, and finally to the loss of the particle at the vacuum chamber. Secondary particles are produced at the impact position by ion-induced desorption and as a result the pressure in the vacuum chamber is increased locally. This local rise in pressure enhances the charge changing processes, and at extremely bad conditions, it can cause an avalanche process resulting in a complete loss of the beam during a few turns in the synchrotron. The layout of the HIAF project is shown in Fig. 1.

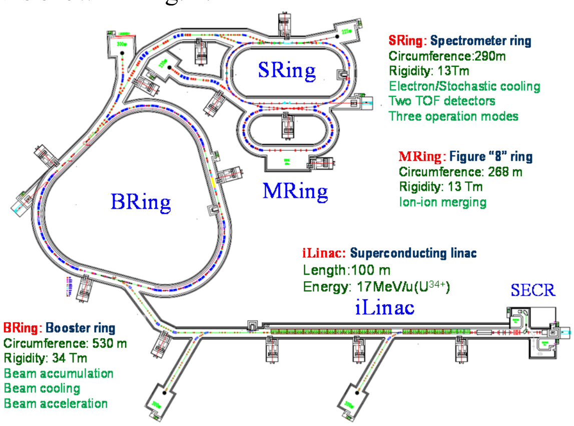

Figure 1: Layout of HIAF project.

BRING COLLIMATION EFFICIENCY

The Booster Ring (BRing) of the HIAF project has a threefold- and mirror-symmetric lattice over its circumference of 530.8 m. Each super period consists of 8 DF structure arc and FODO straight sections. Beam loss distribution is calculated by the new developed simulation program.

In order to simulate the charge exchange driven beam loss and dynamic vacuum effects in heavy ion synchrotrons, a new program package (ColBeam) designed for optimizing the collimation efficiency is developed by taking different types of errors into account in the accelerator [2].

The particles can be tracked in a ring during multiple turns or in a beamline just one-pass. Firstly the software package must load a lattice file which contains essential element parameters of the ring or beamline, such as element type, length, strength, vacuum chamber aperture and so on. The lattice file with extension "LAT" for the simulation software Winagile [3] is used as the default input file.

More than thirty lattices for the Bring have been simulated and the collimation efficiency was optimized. Collimation efficiency is defined as the ration of the particles hitting the collimators N_c and the wall N_w.

$$\theta = \frac{N_c}{N_w + N_c} \tag{1}$$

The final accepted lattice is the DF structure and its collimation efficiency is 100% according to the simulation result. With a constant vacuum pressure around the ring, the

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beam trajectory for one electron-loss $^{238}U^{36+}$ is illustrated in Fig 2. The loss position and intensity of the charge exchanged particle at each point is also counted and shown in the Fig 2.

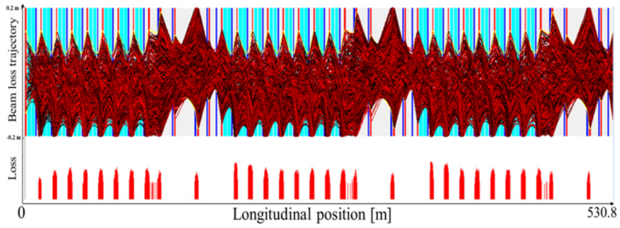

Figure 2: Beam loss trajectory and the beam loss distribution of the simulation results for one electron-loss $^{238}U^{36+}$.

The beam trajectory of the lost beam with the collimator is shown in Fig 3. No beam is lost on the vacuum chamber wall and the collimation efficiency is 100%.

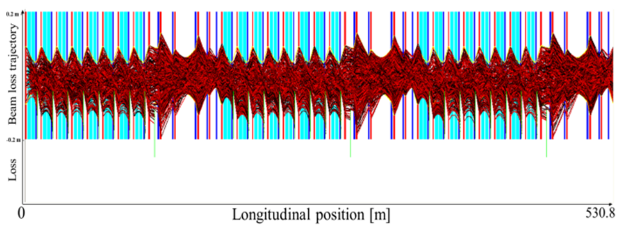

Figure 3: Beam loss trajectory and the beam loss distribution of the simulation results for one electron-loss $^{238}U^{36+}$ with collimators.

GAS DESORPTION MEASUREMENT

Low Energy Measurement Platform

The gas desorption yield experiment has been conducted at the 320 kV high voltage platform in IMP. The 320 kV HV platform, based on the ECR ion source and built in 2007, is the one that can supply 320 kV high voltage and electrostatic acceleration of various high charge state ion beams[4]. This platform can provide stable and continuous low energy heavy ion beams. Figure 4 shows an overview of the experimental setup, including three quadrupoles (Q1~Q3), vacuum chamber (l = 545 mm), a short vacuum chamber (l = 340 mm) as experiment chamber, a slit, a fluorescent screen (VS) with a TV camera, a Faraday cup (FC) and a target. The three quadrupoles at the starting position are used to optimize the beam size. To make sure that the data collected by the vacuum gauge is all from the target, which means all particles should impact on the target surface instead of the vacuum chamber wall, a slit (square: 90 × 90 mm^2) with a small hole (12 mm) is installed in the long vacuum chamber. Behind the slit, a fluorescent screen with a TV camera is used to cooperate with the hole on the slit to ensure that the beam would bombard the target perpendicularly by adjusting the beam to the center of the fluorescent screen. The beam current is measured by the Faraday cup. The target, which is made of oxygen-free copper (cube: 50×50×50 mm^3) and has been cleaned by alcohol first, is installed in a short test vacuum chamber which is located at the end of the beam line.

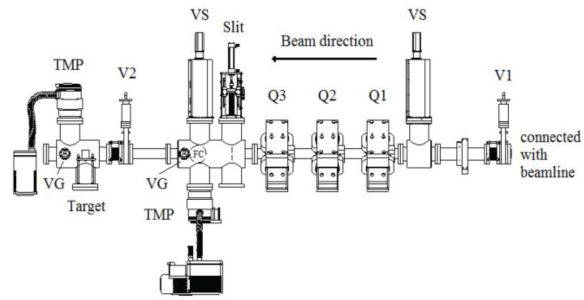

Figure 4: Experimental setup used for ion-induced gas dsorption yield measurement on the 320 kV HV platform at the IMP.

Table 1 lists the beam parameters for the desorption measurement. The spot size of the beam is about 10 × 20 m^2, monitored by fluorescent screen after the slit.

Table 1: Beam Parameters used in the Gas Desorption Yield Measurement

Beam	Charge state	Energy (keV)	Current (μA)
Xe	10+	1000	3.91 ± 0.21
		1500	4.01 ± 0.07
		2000	3.98 ± 0.18
		2500	3.89 ± 0.14
O	1+	100	4.95 ± 0.06
		150	5.20 ± 0.10
		200	5.00 ± 0.06
		250	4.97 ± 0.21

Figure 5 shows a typical pressure evolution in the experimental chamber with the copper target bombarded continuously with 2500 keV Xe^{10+} ions [5].

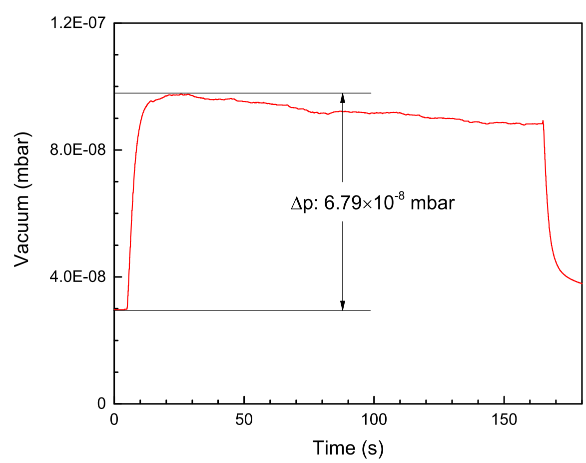

Figure 5: Pressure evolution in experimental chamber during a period of continuous bombardment. The copper target is bombarded by 2500 keV Xe^{10+} beam with a loss about 2.43×10^{12} particles per second.

The results of continuous bombardment measurements of Xe10+ and O+ are shown in Fig. 6. The two figures show the Xe10+ data and O+ data divided by 10 respectively. The chosen energy regimes of Xe10+ beam and O+ beam are both well below the Bragg-Peak, and one can find

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that the measured gas desorption yields are increasing with increase of ion energy. From the Fig.6, it can be seen that in the applied energy regime the nuclear energy loss is dominating for the Xe beam, and the electronic energy loss is dominating for the O beam [6].

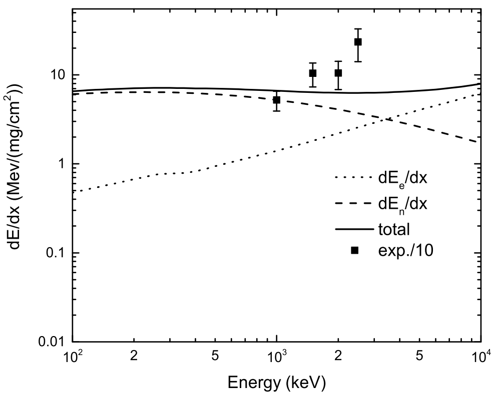

Figure 6(a): Nuclear energy loss dE_n/dx and electronic energy loss dE_e/dx for projectile lost perpendicularly on the surface of copper target for Xe beam.

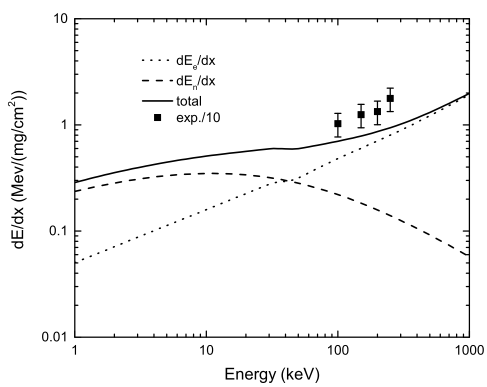

Figure 6(b): Nuclear energy loss dE_n/dx and electronic energy loss dE_e/dx for projectile lost perpendicularly on the surface of copper target for O beam.

High Energy Measurement Platform

High energy experimental setup to measure the ion induced desorption rate is designed and installed at the CSRm. Figure 7 shows the layout of this setup [6].

This setup consists of three chambers: first chamber which installed an Integrating Current Transformer (ICT), Al_2O_3 fluorescence screen is used to measure the beam current and align the incoming beam; the second chamber which installed a TSP, SIP and NEXTorr is used to pump out the desorption gases; the experimental chamber is equipped with a pressure (extractor) gauge and a residual gas analyzer (RGA) to measure the total pressure increase and the partial pressure distribution during ion bombardment.

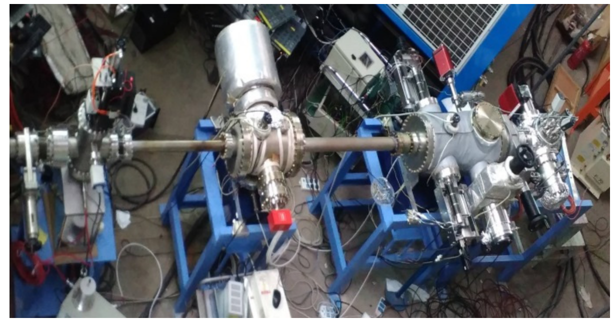

Figure 7: The layout of experimental setup.

The first beam measurement in this setup was conducted in 2015 with the Sn^{26+} beam. The beam intensity was low to decrease the measurement noise. Therefore, more beam with high energy are needed in this setup to measure the gas desorption.

CONCULSION

The heavy-ion induced gas desorption yield measurement shows the relationship between the desorption yield and the beam energy. With the increase of projectile energy, the change of desorption is up to 4 times for Xe beam and 2 times for O beam. The results indicate that the desorption yield scales with the $(dE_e/dx)^2$ roughly.

These results will support future dynamic pressure simulation and optimization of the position and efficiency of the collimators to be installed on the BRing at HIAF, which the gas desorption part of outgassing rate would increase and influence the localized pressure profile when charge-exchanged particles hit chamber wall or collimators in tracking simulation.

ACKNOWLEDGEMENT

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