BEAM DIAGNOSTICS FOR THE PROTOTYPE OF THE CRYOGENIC STORAGE RING CSR

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Abstract

The Cryogenic Storage Ring CSR at the Max Planck Institute for Nuclear Physics (MPI-K) Heidelberg will be a 35m circumference, electrostatic ring, which is mainly dedicated to Molecular- and Atomic Physics experiments. To reach the low pressures (10^{-15} mbar), which are necessary to achieve the required long storage times, the complete ring has to be operated at a temperature below 4K (2K in sections), for which reason it will be installed inside a large cryostat. To prove the novel cryogenics and vacuum concepts of the CSR, we have built up a prototype, which is basically a segment of the CSR, housing an electrostatic ion trap. The ion trap is in the first instance used for vacuum measurements and equipment tests in the XHV range, in a later stage, it shall be an experimental facility of its own. Test operation of the prototype is currently starting. Since the boundary conditions in the CSR are highly demanding for the beam diagnostics system, tests of these devices are mandatory and planned to be performed in the prototype setup. This paper describes the prototype beam diagnostics system and presents first experimental results.

INTRODUCTION

The planned experimental programme of the CSR demands a wide range of ion species, energies and intensities in an environment cooled down to temperatures of 2 K or even less [1]. Additionally to the low temperatures and the XHV conditions, low charge states, low particle velocities and low beam intensities make the technical realisation of the CSR (and all its subsystems) an extremely challenging task. Regarding the beam diagnostics system, table 1 gives an overview of the diagnostics devices we plan to install in the CSR.

Table 1: CSR diagnostics system

Measurement	Device
First Turn Diagnostics / Profile Measurement	Low Intensity Beam Profiler
Bunches / Closed Orbit	Position Pickups (PPUs)
Nondestructive Profile Measurement	Ionisation Profile Monitor (IPM)
Energy Spread / Cooling	Schottky PUs
Beam Intensity	Cryogenic Current Comparator (SQUID)
e^--Beam Profile	Wire Scanner

To prove the CSR cryogenics and vacuum concepts [2, 3] and to investigate the stability and alignment of the whole structure during the cooling down process, a prototype [4] has been built up (see Fig. 1), which is a 3.5 m segment of the CSR, housing an electrostatic ion trap [5]. Since there is no existing technology for vacuum measurement in the given pressure range, we plan to use the recombination rate of ions (e.g. Ar^{1+}), which are injected and stored in the ion trap and subsequently recombine with electrons from the residual gas. Ions which recombine will leave the trap in a straight line and are detected with a neutral detector, consistsing of a multi channel plate (MCP) in connection with a delay line, at the trap exit. From the count rate at this detector we can determine the vacuum pressure, using the cross sections for recombination and multiple scattering.

Presently preparations for an experimental programme using the prototype ion trap are on the way. First measurements will be done to investigate the photo dissociation of Al_4^{1+} clusters. For these experiments a working diagnostics system is required, as well as the diagnostics devices have to be tested under real CSR conditions. In the present setup we have installed a low intensity Beam Profiler, two Position Pickups and a sum Pickup. It is planned to add an Ionisation Profile Monitor to prove the feasibility of such a device in the low gas densities of the XHV.

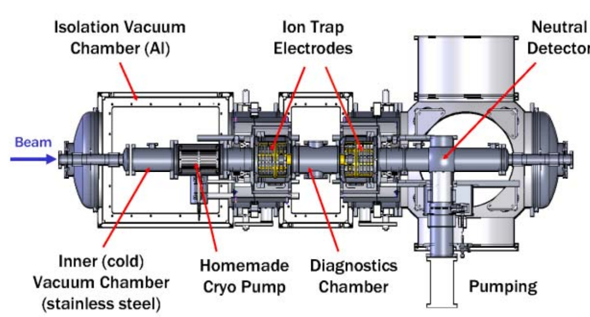

Figure 1: The CSR prototype

LOW INTENSITY BEAM PROFILER

During test of various scintillator materials it turned out, that in the given energy and mass range the surface damage caused by sputtering results in a rapid decay of the scintillation light luminosity. Therefore we replaced the scintillators by a metal plate for production of secondary electrons, observed with a MCP / phosphor screen combination.

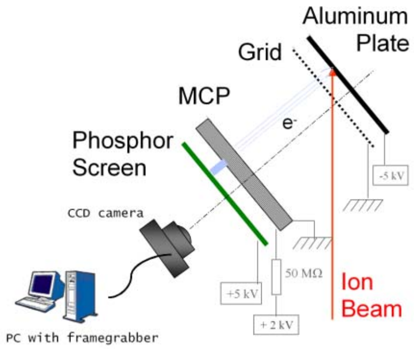

Figure 2: REX-ISOLDE low intensity Beam Profiler

This device has been well tested in the REX-ISOLDE diagnostics system [6]. It requires some additional HV feedthroughs into the cold chamber, but it has the advantage of a high sensitivity and large detection range (1 – 10^{12} particles/s). The system shown in Figure 2 has been installed in UHV chambers and is placed in front and behind the CSR prototype.

During the first set of experiments the Beam Profiler shall also be used for neutral particle detection behind the trap because the neutral detector shown in Fig. 1 is not yet in place. To check the possibility of single ion detection with the REX device, we have performed experiments with a collimated ^{241}Am alpha source, ($E_\alpha = 5.6$ MeV, source activity: 3.7 kBq). During these measurements, a commercially available Beam Observation System (BOS / Beam Imaging Solutions) was placed downstream the REX Beam Viewer, to have a comparison between particle detection when shooting directly into an MCP (BOS) and when using the secondary electron mechanism (REX). Both devices were equipped with 40 mm Chevron MCPs. From earlier investigations [7] we expected a secondary electron yield of ~ 4-5 electrons per ion hitting the Al plate, so in principle an increased detection probability in the REX detector should be observed. In reality we found a count rate in the REX detector, which was (taking into account the different solid angles of the two detector surfaces) mainly determined by the beam attenuation in the acceleration grid. We used an 80% transmission grid, which reduces (under an angle of 45°) the ion intensity to about 55%. Besides this, no effect from different detection efficiencies for ions and electrons (~ 75% for ions with E = 5 keV, open area ratio of 65% for electrons [8]) or from attenuation of the secondary electrons could be clearly identified.

Concerning the imaging properties, we found in the BOS a clearly better picture of a collimator pattern placed at the entrance of the diagnostics chamber (see Fig. 3).

In a next step the REX device could be further optimised, using a grid or alternatively a harp with higher transmission and a stopper plate with higher secondary electron yield (e.g. CuBe). The imaging properties could possibly be improved by simulation calculations and change of the plate/grid geometry. Meanwhile the REX Beam Profiler fullfills our requirements and is an extremely helpful device.

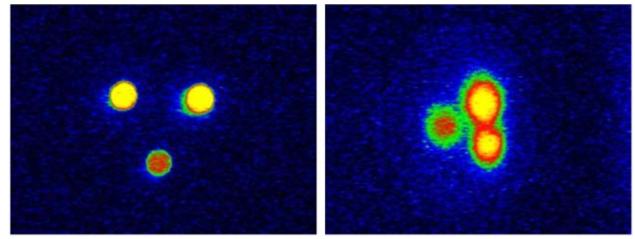

Figure 3: Beam through three 4 mm collimators in the BOS (left) and in the REX Beam Viewer (right).

POSITION PICKUPS

For the ion bunch and position measurement in the center of the ion trap we have built a Position Pickup, which is a compromise between Pickup and Kicker for mass separation. Fig. 4 shows our Pickup, which consists of two fourfold segmented stainless steel rings for position measurements, together with a separated closed ring for bunch detection. The electrodes are fixed with sapphire blocks to an outer carrier ring to have a good thermal contact.

Figure 4: Position and sum Pickups of the ion trap.

For the Kicker function, high voltage is pairwise applied to the upper and lower electrodes of one of the PPUs. Since the setup at the first experiments has no magnetic mass separator, we will do a mass separation analogue to the “rf-knock out” principle in storage rings.

The vertical oscillation frequency in the ion trap is given by:

$$f_y = f_0(n \pm q), \qquad (1)$$

where n is an integer number, q is the non integer part of the tune, f_0 is the mass dependent oscillation frequency in the trap. All ions have the same energy/charge ratio and therefore the same ($n \pm q$). Due to the self bunching effect in this kind of traps, we will - using the sum pickup - obtain a frequency spectrum with separated peaks corresponding to the different ion masses. The knock out can be done selectively by sweeping an rf-voltage (U_{rf} ~ 10 V, frequency range: 50 -100 kHz) over the unwanted species. This process should take only some milliseconds, short enough to cope with the expected measurement and storage times. Alternatively we can apply voltages up to 500 V to the Pickup to kick the unwanted ions out during a single oscillation.

For position measurements we did a calibration of the Pickup with the coaxial wire method. The expected beam current of 1 nA was calculated to a wire voltage of 3 mV, which we could easily see at our Pickup using an ultra low noise amplifier (SA-220F5) from nf company. As expected, it turned out that the behaviour of the pickup is extremely nonlinear, moreover in the linear sections the scaling factor in x is a function of the y-position. This means the measurement of the absolute beam position is problematic because the Pickup geometry results in a set of nonlinear calibration curves. However, what we can detect is the phase jump when crossing the beam axis, but for CSR a better measurement is required. Fig. 5 shows the calibration curves for the x-position at four different y-coordinates.

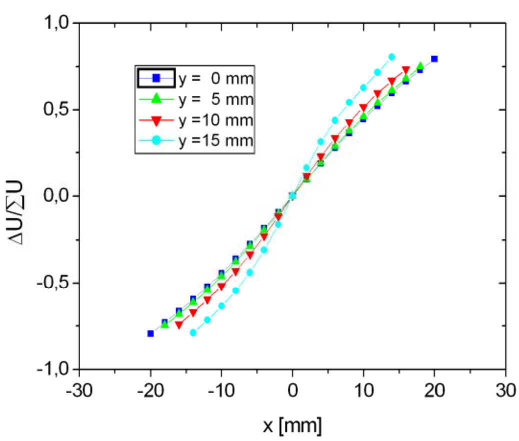

Figure 5: Calibration curves for the prototype PPU.

In parallel to the calibration measurements we tested a resonant Pickup operation, which we consider as an option to increase Pickup sensitivity in the CSR. We used the sum PU with a copper coil (50 windings) connected in parallel, forming a resonant circuit with a resonant frequency of f = 2.1 MHz and a quality factor of Q = 215. With $R = Q/\omega C$ we calculated an impedance of the circuit to ~ 500 kΩ. We connected the circuit directly (no impedance matching) to the input of the preamplifier (1MΩ) and could immediately see an increase of the signal to noise ratio from 22 dB to 44 dB. This is - regarding the comparatively simple setup - an encouraging result.

IONISATION PROFILE MONITOR

At a vacuum pressure of 1×10^{-15} mbar, the count rate for residual gas ionisation by a 300 keV, 1 µA Proton beam is calculated with $R = \sigma\, n\, v\, \eta\, N$ to 10 Hz. Here σ is the ionisation cross section, taken from [9], n is the residual gas density, v is the beam velocity, η is the ratio of effective detector length to ring circumference and N is the number of stored ions.

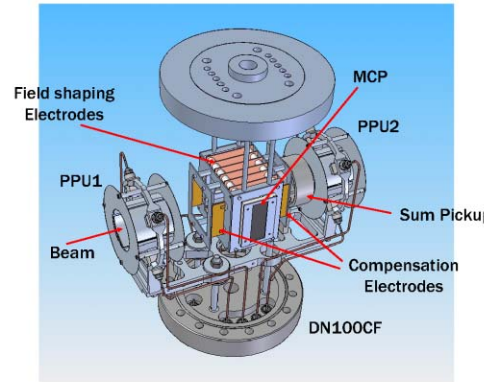

Figure 6: The test IPM mounted together with the PPUs in the experimental chamber of the ion trap.

We have designed a small test IPM, which will be installed in the trap Pickup chamber as seen in Fig. 6, to measure the dependence of the IPM count rate on the vacuum pressure. At the same time we want to test different approaches for creation of a local pressure bump, like e.g. laser heating or gas inlet. The homogeneity of the IPM- field has been calculated with the TOSCA code and is despite its small dimensions (5 x 5 cm open area) nicely homogeneous, so we expect the test IPM to have imaging properties, which make it a useful diagnostics device for our experiments.

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