A BEAM DIAGNOSTICS SYSTEM FOR THE HEIDELBERG CRYOGENIC STORAGE RING CSR

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Abstract

The storage of rotationally non-excited molecules and highly charged ions requires lowest temperatures and vacuum pressures. At the MPI-K Heidelberg a cryogenic storage ring (CSR) for atomic and molecular physics experiments is under development. The CSR shall allow operation at temperatures of 2 K and pressures down to 10^{-15} mbar. The ring consists of electrostatic elements and has a circumference of ~35 m. It is housed inside a large cryostat, cooled by a (20W @ 2K) Helium refrigerator. To reach low UHV pressures already at room temperature the whole machine has to be bakeable up to 300°C. These boundary conditions, together with the low charge states, low velocities and low intensities (1nA-1µA) of the ions, put strong demands on the beam diagnostics system. Some beam parameters like profile, position and intensity cannot be measured with “standard” beam diagnostics technology. Here new or further developments are required.

The paper gives a general view of the beam diagnostics concept for the CSR and shows in more detail possible solutions for measurement of beam position and beam profile.

INTRODUCTION

The planned Cryogenic Storage Ring CSR [1] at the MPI-K Heidelberg is a pilot project to prove the technical feasibility of a 35m circumference storage ring, which is - together with its related devices like electron cooler and reaction microscope - installed completely inside a large cryostat to reach operation temperatures down to 2 K.

At the same time, room temperature operation of the ring shall be possible for commissioning and test purposes. The whole apparatus has to be bakeable up to 300°C because a pressure of 10^{-15} mbar at 2 K requires an extremely good UHV already at room temperature. The overall temperature range of almost 600 K in connection with the UHV/XHV requirements is very challenging concerning mechanical design, materials and vacuum technology.

Looking at the planned range of ion beams, the CSR is not less demanding concerning its particle dynamics, beam diagnostics and electron cooling. Table 1 shows the basic parameters of the CSR at one glance. The mass range of $A \leq 100$ is at the moment considered to be a reasonable design value. Studies with much heavier molecules ($A \leq 2000$) are foreseen in a later stage of CSR operation.

Table 1: Basic parameters of the CSR

Type	Electrostatic
Circumference	35.2 m
Operation temperature	2 - 300 K
Vacuum pressure	1×10^{-15} mbar
Mass range	1 – 100 amu
Energy range (1^+ ions)	20 – 300 keV
Intensity range	1 nA – 1 µA
Revolution Frequency	5 -220 kHz

The general concept for the beam diagnostics system of the CSR is shown in Figure 1. Beam injection takes place in three corners of the ring (molecules, highly charged ions and neutral particles), which requires in each following straight section a device for measurement of beam position and size during injection. This (destructive) measurement will either be done with appropriate scintillation screens or with a multi channel plate (MCP) based low intensity beam profiler (see below).

To measure profile (and position) of the circulating beam, we are investigating the possibility of a Residual Gas Monitor at low pressures. Due to the low residual gas density in the CSR, we have to find a way to increase the pressure locally to 10^{-12} mbar (at < 4 K) to get reasonable count rates. Also MCP operation in such devices is not well tested at the given temperatures.

For measurement of the beam intensity a SQUID based Cryogenic Current Comparator (CCC) like described in [2] is under discussion. Recent tests with these devices at the University of Jena have shown a further increase of sensitivity due to improved superconducting magnetic shielding and electronics [3]. With these CCCs one can expect to measure DC currents below 1 nA in the CSR.

At the beginning and at the end of each straight section (except for the electron cooler) there will be x, y - Beam Position Monitor pickups for the closed orbit measurement. Because of the low beam intensities, we will operate the capacitive pickups in a high Q resonant circuit to achieve highest possible position sensitivity.

The longitudinal Schottky pickup will be either combined with the rf-acceleration tube or (depending on the rf-noise) be installed separately in a corner between the 39° deflectors. It will also be built as a resonant system and benefit from the Q optimisation for the position pickups (PPUs). The possibilities of transverse Schottky measurements and stochastic cooling have not been investigated so far.

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The diagnostics of the electron beam size and position is done with a wire scanner placed inside the HTS solenoid. Since this scanner works also as a scraper for the ion beam, it will allow precise measurements of the relative positions of electron and ion beam.

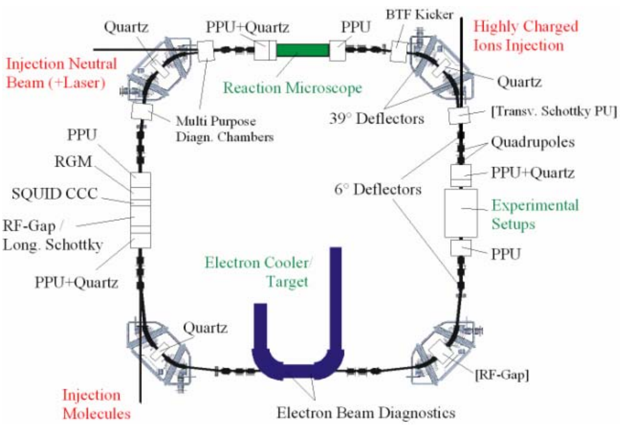

Figure 1: Layout of the CSR beam diagnostics system.

SCINTILLATION SCREEN TESTS

Numerous tests with 20 keV beams of D^+ and Ar^{1+} ions at 1 nA - 1 µA have been performed to find an appropriate scintillator material for our application. Among the tested materials (BeO, Chromox6, Ruby, ZrO2, Quartzglas, BN, YAG) the BeO and the YAG showed the best performance, followed by the Chromox6 (Al2O3+CrO2). Using a WATEC 902H camera (sensitivity 300 µLux), beam profiles could be measured with the Ar beam down to 80 nA, with the D beam down to 1 nA at spot sizes of 10x20 mm.

However, after several hours of irradiation with the deuterons and after only a few minutes of irradiation with the Ar (pressure: 10^{-7} mbar), a drastical irreversible decrease of luminosity was measured for all materials. On the irradiated surfaces of the scintillators brown or black traces were observed. Since thermal damage could be excluded, we checked with EDX (Energy Dispersive X-Ray Microanalysis) the element abundances inside and besides the irradiated areas. No significant differences in chemical composition (e.g. the amount of Carbon) could be found, which is in agreement with similar results at LEIR/LHC [4].

If it turns out that in the given energy and mass range the damage caused by sputtering is too heavy for any material, the scintillator has to be replaced by a metal plate for production of secondary electrons, observed with a MCP / phosphor screen combination (see Fig. 2). This device has been well tested in the REX-ISOLDE diagnostics system [5]. It requires three additional HV feedthroughs into the cold scintillator chamber, but it has the advantage of high sensitivity and large detection range (10^3 – 10^{12} particles). The operation of MCPs at 6 K was recently successfully tested at MPI-K for the CSR reaction microscope [6].

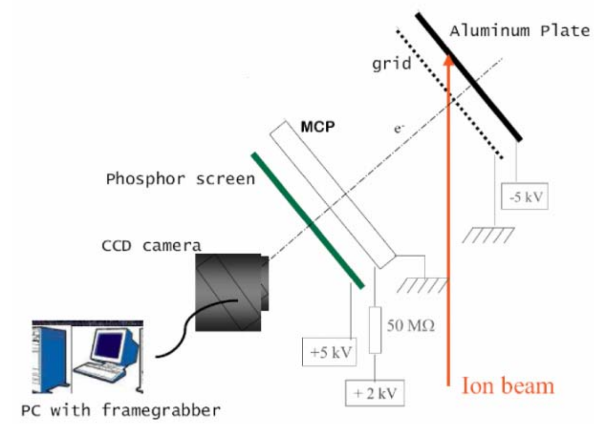

Figure 2: Low intensity beam profiler.

BEAM POSITION MONITORS

In the CSR a stored beam of 1 nA, 300 keV, A = 3 ions induces at a pickup capacity of 80 pF and high input impedance (1 MΩ) of the head amplifier a voltage signal of 340 nV. With a scaling factor of 200 mm one can calculate the differential signal for a beam displacement of 0.5 mm to 870 pV. Even with ultra low noise amplifiers (voltage noise: 0.5 nV/$Hz^{1/2}$) like developed for the CERN AD closed orbit measurement system [7] and additional bandwidth reduction, it is extremely difficult to separate these weak signals from the background noise.

For that reason we plan to build the CSR capacitive pickups as part of a high Q resonant circuit and benefit from the narrow bandwidth and high shuntimpedance of such a system. With a given capacity of the pickups of 80 pF, the required inductance to reach the bunch (and revolution) frequency of the CSR is 10 mH. Using 3B7 and 3H1 Ferrox Cube P-Cores and regular copper wires we reached Q-values of around 150 and (by adding a capacitive diode) managed to tune the system in a frequency range from 60 kHz to 250 kHz (whereby the Q values went down to 70 - 30 because of losses in the diode). Since we expected mechanical problems and changing of the μ_r during the cooling process - and also looking at encouraging results in the ion trap development [7] - we finally decided not to use ferrites and go for cooled air-core coils with n ≈ 1000.

To first demonstrate the feasibility of the concept at an existing machine, using a real ion beam instead of a coaxial wire, we started with coils with n = 50 to reach the bunch frequency of the Heidelberg TSR (TestSpeicherRing) of 3 MHz. Currently we have achieved Q values of >500 with coils made of normal copper wire, turned on a Teflon tube and cooled down to 78 K. The next steps will be to further optimise the coils for higher Q and to go to lower temperatures. Furthermore the coil will be installed inside a copper shielding (helical resonator) to avoid losses and to reduce noise. Finally the coupling from the resonant circuit to the head amplifier input has to be optimised.

BEAM PROFILE MEASUREMENT

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 [8], 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.

A count rate of 10 Hz is slightly above the MCP noise and does not allow for reasonable beam profile measurements. Since it is not acceptable to extend the integration time (electron cooling times: 1 - 10s), we consider the possibility of increasing the pressure to at least 10^{-12} mbar in a short, well defined section of the ring.

A possible solution is shown in Figure 3. The RGM electrodes and MCPs are housed in a box with cold walls, which shall immediately pump the gas (N_2) produced by heating of the electrode surfaces. The additional heat load is in the mW range and therewith acceptable from cryogenics point of view. The electrodes are switchable from x to y-profile measurement to keep the device as short as possible. Outside the box, correction electrodes are mounted (with thermal contact to the cold box) to compensate for the beam displacement by the RGM electrodes and to provide additional pumping. The required electrode voltages are comparatively small due to the low temperature. We calculated the field geometry with the TOSCA© code and found reasonable projection and ion trajectories for voltages of ±50 V in both coordinate directions.

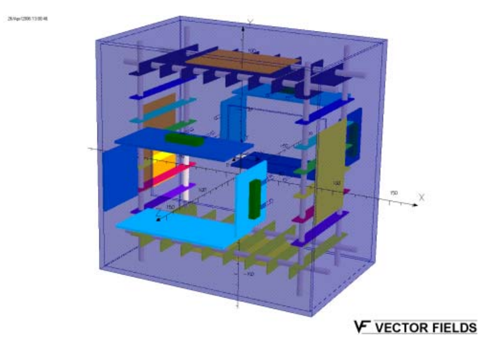

Figure 3: CSR Residual Gas Monitor.

An additional complication arises from the fact that the RGM measurement is not fully non-destructive. A beam intensity of 1 nA means at a revolution frequency of 50 kHz a number of $\sim10^5$ particles in the ring. At a count rate of 1 kHz, a measurement during 20 s destroys a significant fraction of such a beam. The situation becomes even worse if one considers the higher cross section for charge exchange at lower beam velocities - a problem which might be solved by using an Ar gas inlet instead of heating the electrodes. Both schemes of vacuum manipulation will be tested inside the ion trap of the CSR prototype, which is currently under construction.

ELECTRON BEAM DIAGNOSTICS

The adjustment of the circulating ion beam relative to the electron beam inside the cooler solenoid is one of the cruicial points during all experiements at the TSR electron target. To have for the CSR an accurate beam diagnostics at this place, we accepted two 20 mm interruptions of the cooler solenoid, 300 mm from the entrance and exit of the 1.84 m high temperature superconducting coil [9]. At these positions wire scanners for the electron beam, which shall (in connection with the PPUs or the SQUID) also work as scrapers for the ion beam, will be inserted into the cold chamber.

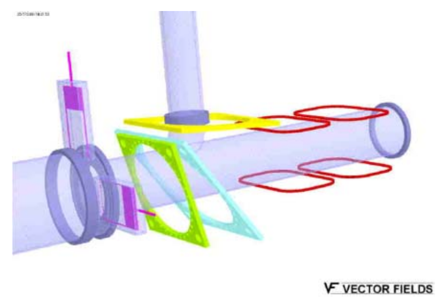

Figure 4: CSR electron beam diagnostics. The ion beam circulates from the right to the left. The electron beam comes throught the vertical tube and is bent to the left. The solenoid with the x and y-wire scanners at its entrance is located to the left. The magnetic shielding around the cooler is not seen in the picture.

REFERENCES

[1] A. Wolf et al., The Heidelberg CSR: Low-Energy Ion Beams in a Cryogenic Electrostatic Storage Ring, Proc. COOL05, Galena, USA (2005), p. 473

[2] A. Peters et al., A Cryogenic Current Comparator for Nondestructive Beam Intensity Measurements, Proc. EPAC94, London, UK (1994), p. 290

[3] W. Vodel et al., this conference

[4] T. Lefèvre et al., Scintillating Screens Study for LEIR/LHC Heavy Ion Beams, Proc. DIPAC05, Lyon, France (2005), p. 57

[5] P. Van den Bergh et al., The REX-ISOLDE Beam Diagnostics System, CAARI, Denton, USA (2000), AIP conf. proc. P. 235

[6] K. U. Kühnel (MPI-K, HD) private communication

[7] C. Weber et al., FT-ICR a Non-Destructive Detection for Online Mas Measurements at SHIPTRAP, Eur. J. Phys. A 25, s01, 65-66 (2005)

[8] D.S.F. Crothers, J. F. McCann, Ionisation of Atoms by Ion Impact, J. Phys. B,: At. Mol. Phys. 16 (1983) p. 3229

[9] H. Fadil et al., this confererence

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