BEAM DIAGNOSTICS DEVELOPMENT FOR THE CRYOGENIC STORAGE RING CSR

T. Sieber, H. Fadil, M. Grieser, R. von Hahn, A. Wolf
Max Planck Institut für Kernphysik, 69117 Heidelberg, Germany

Abstract

A cryogenic storage ring (CSR) is under construction at the MPI-K Heidelberg. It consists of electrostatic elements and has a circumference of ~35 m. The CSR shall be used for storage of rotationally non-excited molecules and highly charged ions, therefore extremely low temperatures (<4K) and gas pressures (10^{-15} mbar) are required. The ring shall also be operational at room temperature and bakeable to at least 300°C. The maximum energy of singly charged ions is 300 keV, the intensities will be in the range 1 nA – 1 µA. For the mass range, A<100 is taken as reasonable design value, in later stages of CSR operation experiments with heavier ions are foreseen.

Due to the exceptional boundary conditions we are working on new or further developments for most of the diagnostics devices. For example our RGMs have to produce their own local pressure bumps. The MCPs have to work at temperatures around 4 K. The beam position pickups shall be operated in resonant mode for increased sensitivity. Our beam profiler will use secondary electrons from a stopper plate, which allows beam imaging in the intensity range 10^2 to 10^{12} pps. For intensity measurements a SQUID CCC system is under discussion.

INTRODUCTION

The planned experimental programme of the CSR [1] covers a wide range of ion species, energies and intensities. Low charge states, low velocities and low intensities put - besides temperature and XHV - strong demands on the beam diagnostics system. Table 1 shows some basic parameters of the CSR at one glance.

Table 1: 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

A possible layout of the CSR beam diagnostics system is shown in Figure 1. Molecules, highly charged ions and neutral beams are injected in three corners of the ring, which requires in the following straight sections a device for measurement of beam position and size during the injection procedure. For this measurement a multi channel plate (MCP) based low intensity beam profiler (see below) will be used.

To measure the profile and position of the circulating beam, a Residual Gas Monitor has to be adapted to XHV conditions. To get count rates around 1 kHz on the MCP, the pressure has to be increased locally to 10^{-12} mbar (at < 4 K). MCP operation at these low temperatures is not well tested, but recent results at MPI-K and Manne-Siegbahn Laboratory look promising [2].

The beam intensity is planned to be measured with a SQUID based Cryogenic Current Comparator (CCC) like described in [3]. The resolution of these devices has currently reached ~100 pA/Hz$^{1/2}$, which would be sufficient for our application. However, extensive R&D is necessary to make the CCC bakeable, to optimise the magnetic shielding and to make the SQUID itself demountable.

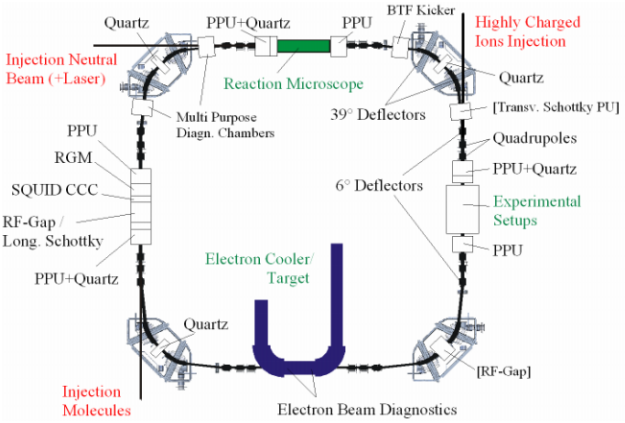


Figure 1: Layout of the CSR beam diagnostics system

At the entrance and at the exit of each straight section there will be Beam Position Monitor pickups for closed orbit measurement. Like proposed for single particle measurements in ion traps, we are looking into the possibility to operate the capacitive pickups in a resonant circuit with high shunt impedance to increase pickup sensitivity.

The diagnostics of the electron beam size and position is done with a wire scanner placed inside the HTS solenoid of the electron cooler. 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.

THE LOW INTENSITY BEAM PROFILER

Numerous tests with have been performed to find an appropriate scintillator material for our first turn diagnostics. We found that in the given energy and mass range the damage caused by sputtering was too heavy for all the materials we checked [4]. Comparable to measurements at LEIR and Linac3 [5] we measured a drastical decrease of luminosity after some hours of irradiation. For that reason (and moreover because of the limited sensitivity and intensity range of any scintillator material) we replaced the scintillator by a metal plate for production of secondary electrons, which are - after passing an acceleration grid - detected on an MCP / phosphor screen combination to produce an image of the beam (see Fig. 2). This device has been well tested in the REX-ISOLDE diagnostics system [6]. It requires three additional HV feedthroughs into the CSR cold chamber, but has the advantage of high sensitivity and large detection range (10^2 – 10^{12} particles per second).

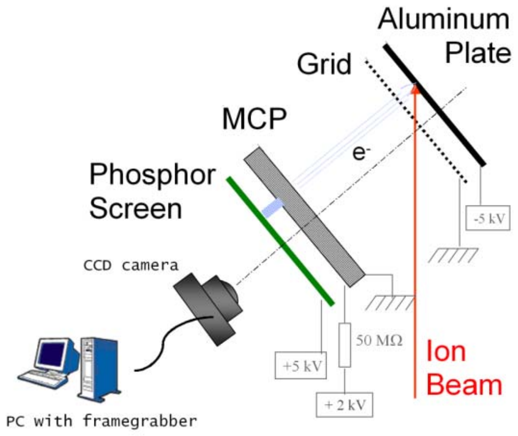


Figure 2: Low intensity beam profiler.

For the injection beamline of the CSR prototype, which is currently under construction, we have built a diagnostic box, housing the device shown in Fig. 2. Figure 3 shows the mechanical layout of this box.

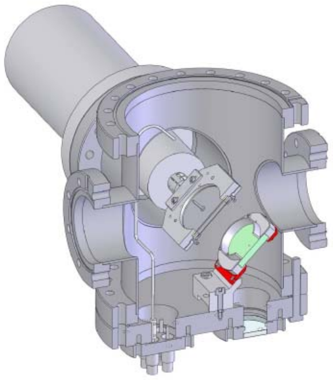
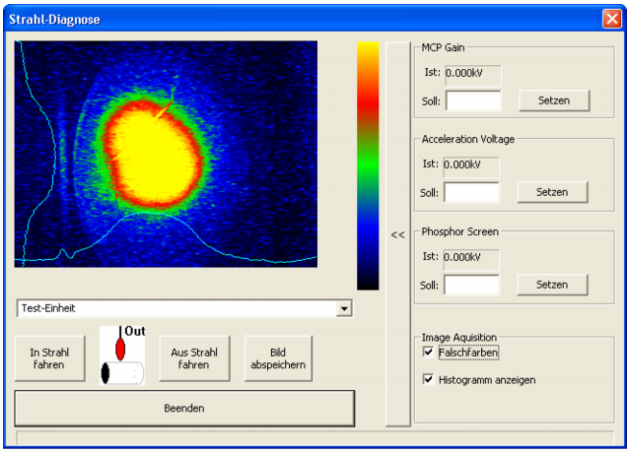


Figure 3: Diagnostic Box with beam profiler.

For control of the voltages of acceleration grid, MCP and phosphor screen, a control program has been developed, which shows the beam (optionally in combination with a beam profile) in artificial colours and is equipped with some reasonable functions, like avoiding movement of components under high voltage and slow changing of MCP and phosphor screen voltages. Figure 4 shows a screenshot of the program, during measurement of a 20 keV, 1 nA H_2^+ beam at the CSR prototype injection beamline. The beam in the picture has a diameter of about 15 mm. In the background, the shape (blue oval) of the 40 mm phosphor screen can be seen.



Strahl-Diagnose

MCP Gain
Ist: 0.000kV
Soll:

Acceleration Voltage
Ist: 0.000kV
Soll:

Phosphor Screen
Ist: 0.000kV
Soll:

Test-Einheit

Image Aquisition
☑ Falschfarben
☑ Histogramm anzeigen

Figure 4: Control program for profile measurement.

Our further developments foresee to optimise the beam profiler mainly with respect to electron production efficiency, transmission of the grid and imaging properties (in dependance on geometry and acceleration voltage). The device could also be very interesting for the CSR experimental setups, as a single particle detector.

BEAM POSITION MONITORS

In the CSR a stored beam of 1 nA, 300 keV, A = 3 ions induces at a pickup capacity of 80pF and high input impedance (1 MΩ) of the head amplifier a voltage signal of about 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 and additional bandwidth reduction, it is extremely difficult to separate these weak signals from the background noise.

For that reason we are investigating the possibility 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 we finally decided not to use ferrites and go for cooled air-core coils with $n \approx 1000$.

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. With a 80 pF vacuum capacitor (simulating the pickups) we achieved Q values of >500 with coils made of normal copper wire, turned on a Teflon tube and cooled down to 78K. For the frequency tuning we consider (so far) an antiquated mechanical variable capacitor as the best solution. We tested a 10 - 260 pF capacitor at our setup, tuning the frequency from 1.5 to 3.5 MHz and managed to have a Q of 200 - 230 at room temperature! However, at n = 700, the resonant circuit still suffers from high C of the coil and parasitic resonances, so for low frequencies a lot of optimisation work is still necessary.

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 [7], 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 – 10 s), we consider the possibility of increasing the pressure to at least 10^{-12} mbar in a short, well defined section of the ring. At the moment we discuss two possible solutions for the production of this pressure bump. Either we will heat one or several components of the RGM with a laser, or install a gas inlet. Laser heating is the more practicable solution, but does not allow to define the gas species (for example noble gas to avoid charge exchange).

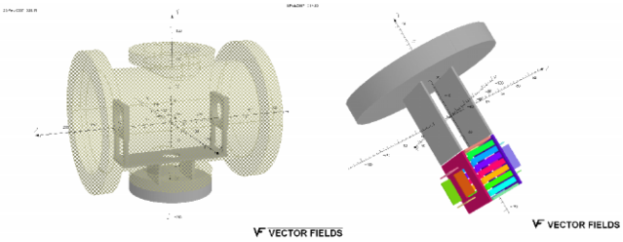


Figure 5: Ion trap test chamber with BPM pickups (left). The laser light comes from below, the RGM (right) will be mounted from above.

Both alternatives will be tested in the CSR prototype, which is in an advanced state of construction and is in principle a short section of the CSR cryostat, housing an electrostatic ion trap. TOSCA© calculations have been performed to fix the geometry of a small 5 x 5 cm RGM, mounted on a CF100 flange, which shall be installed inside the test chamber of the ion trap. The required electrode voltages are comparatively small due to the low temperature. We calculated reasonable ion trajectories and imaging for voltages of ±50 V.

ELECTRON BEAM DIAGNOSTICS

To have an accurate beam diagnostics for the adjustment of the electron cooler beam to the ion beam, 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. At these positions wire scanners for the electron beam, which shall (in connection with the PPUs or the SQUID CCC) also work as scrapers for the ion beam, will be inserted into the cold chamber. The construction of the CSR electron cooler is currently starting.

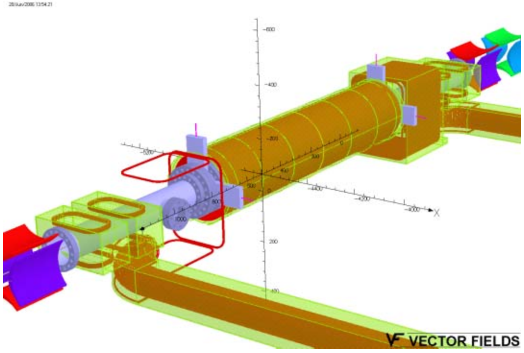


Figure 6: Mechanical layout of the CSR electron cooler with the electron beam diagnostics. The ion beam circulates through the thick beam tube (solenoid). The electron beam comes perpendicular through the thinner, U-shaped tube. The x,y wire scanner/scraper is located at the entrance and exit of the solenoid.

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