

CSR - A CRYOGENIC STORAGE RING AT MPI-K

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Abstract

A small cryogenic storage ring is presently being developed at MPI-K, Heidelberg. The energy in the machine will be variable from 20 keV to 300 keV. Electron cooling will be applied to produce a high quality ion beam. The ring shall accommodate slow, vibrationally and rotationally cooled molecular ions and highly charged ions from the EBIT ion source [1]. Moreover, it will serve as a test facility for the low-energy antiproton ring planned within the FLAIR collaboration [2, 3] to be installed at the future GSI facility. A number of technological challenges have to be handled: Especially highly charged ions at low energies require a vacuum in the order below 10^{-13} mbar to achieve reasonable lifetimes. Therefore - and for enabling experiments with rotationally cold molecules - the complete machine will be cooled down to below 5 K. Moreover, experiments with reaction microscopes to determine the full kinematics of ion-atom or molecule collisions require a bunched operation with a bunch length less than 2 ns. The preliminary design of the machine, its optical elements and the lattice functions are given and first ideas about the vacuum chamber design are described in this paper.

INTRODUCTION

In recognition of the increasing demand on quantum state preparation and kinematical control in atomic and molecular reaction studies, options for enhancing the quality of low-energy ion beams have been studied at the Max-Planck Institute for Nuclear Physics, which now have converged to the design of a unique next-generation electrostatic ring for storing low-energy beams of essentially all ion species – molecular ions, macro- and bio molecules, clusters, atomic ions at extreme charge states, and even antiprotons. The ring can be operated at both room temperature and cryogenic temperatures below 5 K.

At unequalled low radiation and matter densities (absence of thermal blackbody radiation and ultra low rest gas pressures) this storage ring offers unique and unprecedented possibilities to study the dynamics of ionic quantum systems under well defined conditions and in hitherto not achieved precision.

LATTICE DESIGN

The symmetric ring lattice consists of electrostatic cylinder deflectors and quadrupole doublets. In each corner section, the overall 90° bend is split up into two 6° deflectors with a mean radius of 2 meters, an electrode distance of 120 mm and two 39° deflectors with a central radius of 1 meter and an electrode distance of 60 mm. This separation has many advantages: Injection of the ion beam to be stored, but also of merged neutral, electron or laser beams, can be realized along a straight line, detection of neutral particles created is possible at the end of each straight section and charged fragments can be detected at different positions in the corner section.

For that purpose, two large detector chambers are placed after the reaction microscope [4, 5] and the electron cooler.

Transverse control of the beam dimensions is done by means of quadrupole doublets placed before and after each corner section. These also house the vertical steerers that will be used for closed orbit correction [6]. An overview of the complete machine is given in Fig. 1.

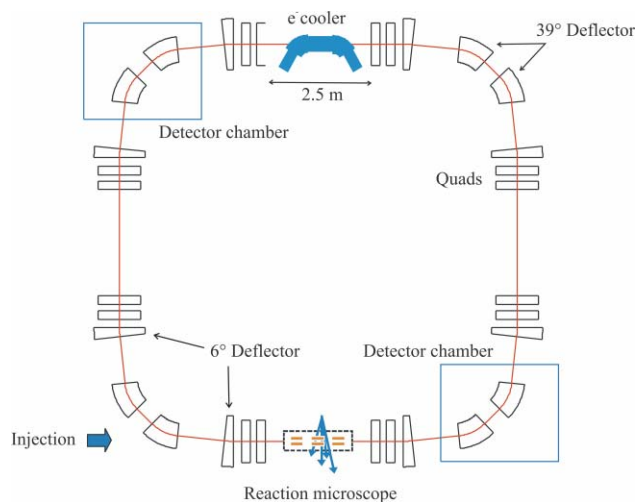


Figure 1: Overview of the cryogenic storage ring

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For all the envisaged experiments, a detailed analysis of the motion of the design beam as well as the motion of the neutral and charged fragments was performed. As one example, Fig. 2 shows the calculated motion of different ions after charge exchange, $|\Delta q/q|=1\%...3\%$. A clear separation between the original beam and the different fragments can be achieved after the first corner and even small changes in the charge state can be detected.

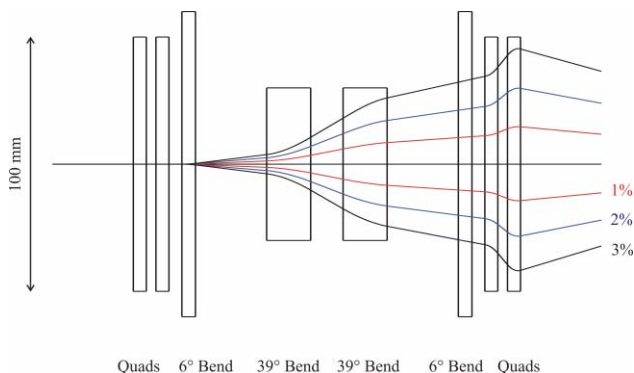


Figure 2: $|\Delta q/q|=1\%...3\%$ separation in the cryogenic storage ring as calculated with COSY infinity

DESIGN DETAILS

New concepts have to be developed for a machine to be operated at both room temperature and below 5 K. The vacuum pressure in the former case has to be in the order of $5 \cdot 10^{-11}$ mbar to guarantee reasonable lifetimes while it should be below 10^{-13} mbar at cryogenic temperatures. Over a temperature range of 500 degrees, a positioning accuracy better than 0.3 mm has to be guaranteed, combined thermal/electric feed-throughs have to be developed and XHV concepts have to be applied for the design of each element.

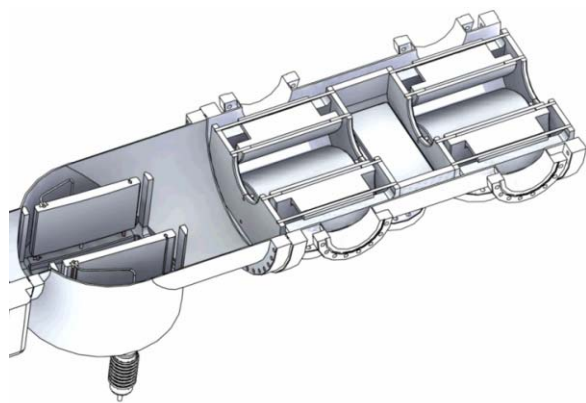


Figure 3: Ring section consisting of a 6° cylinder deflector and a quadrupole doublet with an integrated steerer

Figure 3 shows the 6° cylinder deflector and the quadrupole doublet with the integrated vertical steerer used for closed orbit correction located in the innermost vacuum chamber. In order to finally achieve a vacuum pressure below 10^{-13} mbar, a 'multi-layer' chamber design as shown in Fig. 4 has to be used.

The outermost stainless steel chamber will be pumped down to 10^{-6} mbar, limiting the heat input to thermal radiation from the room temperature walls. A 40 K shield plus additional super-insulation (not shown in Fig. 4) absorb the heat input of about 400 W/m^2 and shield the innermost 2 K structure.

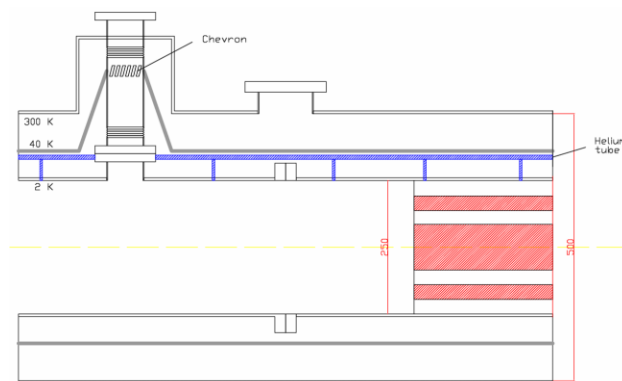


Figure 4: Possible layout of the cryogenic vacuum chamber. The machine will be operated at both room temperature and below 5 K.

A compromise has to be made between high pumping efficiency and low thermal conductance. By using a 'chevron type' shield, the 300 K radiation load can be reduced to below 10^{-3} of the unshielded value, while providing 0.25 of the full molecular conductance to the pumping surface [7].

Extensive calculations and discussions are ongoing to solve the various challenges of this next-generation machine, especially the vacuum pumping concept, the baking possibility, the selection of adequate materials and of course the possible cooling procedures.

Different designs are under consideration, but we plan to start the fabrication of prototype chambers already within 2004.

ELECTRON COOLER AND REACTION MICROSCOPE

Due to the low energy of the circulating beam, also the matched electron energy in the cooler region has to be extremely low. The development of the cooler is ongoing and based on the experience with the TSR cooler [8], [9]. Some example parameters are presented in table 1.

Table 1: Parameter of the electron beam for some specific ion species

<i>energy [keV]</i>	<i>species</i>	<i>e⁻ energy [eV]</i>
300	p	164 eV
300	H ₃ ⁺	54 eV
300	O ₂ ⁺	5.1 eV
300	<i>m = 100 amu</i>	1.6 eV
10	p	5.5 eV

Collision experiments of the circulating beam with a cold Helium gas jet within the reaction microscope require a well defined time structure of the beam. For singly charged ions, pulse lengths in the nanosecond regime should be envisaged – requiring rf rebunching and strong electron cooling in both transverse and longitudinal phase space.

The fields in the cylinder deflector always lead to a coupling between transverse and longitudinal motion and unavoidable longitudinal dispersion of the beam. At low energies, this effect is increased by the high intra beam scattering rates. Systematic investigation of the longitudinal equilibrium between cooling and intra beam scattering will be done this year at the TSR.

The present design parameters of the CSR are summarized in table 2.

Table 2: Summary of the ring parameters

<i>General Parameters</i>	
Energy range	20 keV – 300 keV
Circumference	33.92 m
<i>6° deflectors</i>	
Plate area	240 mm x 220 mm
Plate distance	120 mm
Central radius	2000 mm
Voltage U	< 20 kV
<i>39° deflectors</i>	
Height	160 mm
Radii	970 mm and 1030 mm
Shield distance	15 mm
Voltage U	< 20 kV
<i>Quadrupoles</i>	
Length	200 mm
Distance between lenses	150 mm
Aperture radius	50 mm
Shield distance	10 mm
Voltage	+/- 6 kV
Steerer length	100 mm
Steerer plate distance	120 mm

CONCLUSION

In the cryogenic storage ring ion beams will be stored at temperatures down to 5 Kelvin under extreme vacuum conditions with corresponding, extraordinarily long storage times, so far only realised in small-scale cryogenic ion traps. It will be possible to store slow beams of molecular ions in a wide mass range (up to clusters and bio-molecules) and atomic ions. Equipped with a reaction microscope and an electron cooler, a very flexible machine in terms of feasible experiments will be build up.

On the other hand, numerous challenges have to be faced: Cryogenic temperature to reach ultimate residual gas pressures below 10⁻¹³ mbar, stable operation over a wide temperature range, electron cooling at lowest energies, high precision beam diagnostics in a cold environment and nanosecond pulse length are only a few examples.

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