THE CRYOGENIC STORAGE RING PROJECT AT HEIDELBERG

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Abstract

At the Max-Planck-Institut für Kernphysik (MPIK) in Heidelberg a next generation electrostatic storage ring at cryogenic temperatures is under development. The main perspective of this unique Cryogenic Storage Ring (CSR) is the research on ions, molecules and clusters up to biomolecules in the energy range of 20-300 keV at low temperatures down to 2 K. The achievement of such temperatures for all wall materials seen by the ions in the storage ring not only causes a strong reduction of black body radiation incident onto the stored particles, but also acts as a large cryopump, expected to achieve a vacuum of better than 10^{-15} mbar (corresponding to 10^{-13} mbar at room temperature). The low temperature and the extremely high vacuum (XHV) will allow novel experiments to be performed, such as rotational and vibrational state control of molecular ions during their interaction with ultra-low energy electrons and laser radiation. A 2 K/21 W refrigerator was successfully commissioned. The connection with a fully assembled cryogenic prototype ion trap is finished and results of first cooling tests will be presented. In this paper we describe the concept and the status of the CSR.

INTRODUCTION

In the last decade appreciable interest concentrated on the exploration of the interaction between molecules and electrons, especially by the investigation of dielectronic recombination processes. Experiments at the Test Storage Ring TSR showed that there is a strong dependence of the recombination cross section on the internal quantum state [1]. To preserve well-prepared quantum states, a wall temperature seen by the molecules of lower than 10 K is required. The possibility of controlling the wall temperature between 10 K and room temperature is desirable. In addition the velocity of the ions should be very low to open a new window in molecular and highly charged ion physics.

Due to the low ion velocity XHV is required for reaching reasonable storage times, achievable by cryopumping hydrogen (the dominant residual gas) only at very low temperatures. A temperature of about 2 K therefore at several positions in the ring is necessary. A system was designed to achieve these temperatures with a helium refrigerator.

The whole storage ring will be electrostatic to cope with heavy ions ranging up to biomolecules. For the above mentioned experiments, the CSR will be equipped with internal targets e.g. an electron cooling device and a reaction microscope. Figure 1 shows the schematic layout of the cryogenic storage ring area.

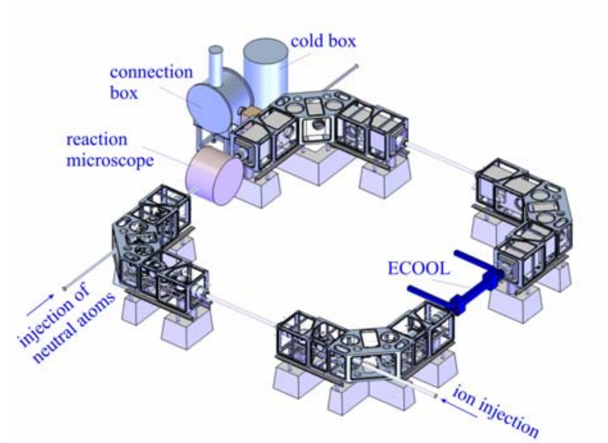

Figure 1: Schematic layout of the CSR with the internal targets and some components of the refrigerator.

GENERAL CONCEPT OF THE CSR

The CSR will have four straight sections dedicated to diagnostics and experiments. Four corners with bending electrodes of 6°, 39°, 39° and 6° each will allow the injection and detection of ions of a large range of ionic masses. The ion-optical layout was optimized by intensive simulations carried out with the programs TOSCA, Cosy Infinity and MAD [2].

The vacuum system of the CSR will be built with different shells in an onion-skin principle. The innermost one is the experimental or cold chamber (manufactured from stainless steel), housing the ion optical electrodes of the electrostatic dipoles and quadrupoles. This chamber will utilize helicoflex sealing technology. The temperature here will be below 10 K, and at specific positions below 2 K. The outer two shells are shields at fixed temperatures (40 and 80 K, respectively) to reduce the radiation onto the experimental chamber. The outermost shell is the room temperature chamber, made from aluminium plates with an aluminium or stainless steel frame. The vacuum of the outer chamber will be completely separated from the inner one, providing the insulation vacuum in the 10^{-6} mbar range.

THE REFRIGERATOR

The CSR requires a complex cryogenic system with two autonomous circuits at different temperatures dealing with varying thermal loads. For an efficient and economical operation of the overall system the experimental circuits have to be closely integrated into the cryogenic plant. Besides the commercially available standard cold box of a Linde 4.5 K helium liquefier an additional connection box was designed to connect the helium vacuum pump needed for 1.8 K operation with individual helium transfer lines and additional heat exchangers to the experiment's cooling circuits [4].
The specified guaranteed cooling powers of 21 W at 2 K or 10 W at 1.8 K, respectively, were demonstrated during the acceptance test period in 2007, and a remarkable spare cooling capacity was achieved during further optimisation operations up to now. In addition the maximum cooling power presently is only limited by the capacity of the helium pump and not by the refrigerator itself. So by adding a more powerful pump the cooling capacity can be still increased.

Figure 2: The connection box with a height of about 5 m and a diameter of 1.6 m. At the right side (red stripes) a heater box for acceptance tests is visible. After removing the heaters the connection box was coupled to the experiment.

For the purpose of testing the cooling power the connection box (see Figure 2) is equipped with at a dummy load with heating modules for the 2 K circuit and the 40 K shield circuit.

THE PROTOTYPE

In order to test some of the newly developed methods and procedures and to check our cooling system a linear prototype cryostat with a length of about 4 m has been designed and built. It is equipped with an electrostatic ion trap to store ions with energies of 3-10 keV. From the measured storage time of these ions the achieved vacuum can be calculated. Thus, the prototype will not only be used as a cryogenic, bakable technology test bench but will also act as an advanced vacuum gauge. In Figure 3 a scheme is shown. Besides the already mentioned components a cryopump is installed. This is a specially developed version which will allow baking the charcoal loaded pumping surfaces to 600 K [3].

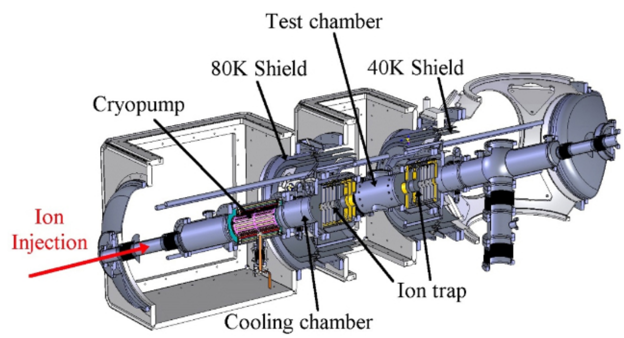

Figure 3: Scheme of the prototype with ion trap, cooling units, cryopump and cooling tubes.

The inner chamber is suspended from the outer one by wire spokes, which are in part spring-loaded. Two cooling units are used to cool the inner chamber to 1.8 K [4].
The prototype cryostat was connected in May 2008 to the refrigerator and cooled down. In this first test period of two weeks the suspension method could be successfully tested showing a deviation of the axis below 0.2 mm during the cool down [5]. However, due to adjustment difficulties, the high asymmetric mass distribution especially in the corners, and the complexity caused by the high number of wires, this method will not be adapted for the final CSR version. Also a few other techniques applied within the prototype will not be used for the CSR, e.g., the cooling units will be integrated in the chambers due to space arguments and TIG (Tungsten Inert Gas) and orbital welding with filling material will be preferred to electron beam welding [5].

THE STORAGE RING

As for non-cylindrically symmetric systems the wire suspension technique was found to lead to problems the support of the cold ion optical elements of the CSR had to be redesigned completely. In the solution found, we completely decouple mechanically the electrodes from all massive internal parts (e.g. chambers). Thus, stems instead of wires will be used to support the electrodes from the bottom. These stems will anchor the electrodes directly to the massive support structure of the ring. They are decoupled from the outer and inner chambers by bellows and will consist of a combination of materials to reduce the heat flow, starting with a glass-filled epoxy resin (G10) support, followed by meandric stainless steel cylinders. These components will be thermally anchored at the shields. The first result of this technique is that the design of the outer chamber (as shown in Figure 4) is now much simpler and can be manufactured without delays caused by waiting for the completion of details in the cryogenic design.

As the ion optical components are mechanically decoupled from the inner chamber, a movement of the inner chamber by several mm during the cool down of the system can now be tolerated. A more rigid base plate, which forms part of the 40 K shield, is used to support the inner chamber by meandric stems. Similar stems are used to support the 40 K base plate from the outer chamber.

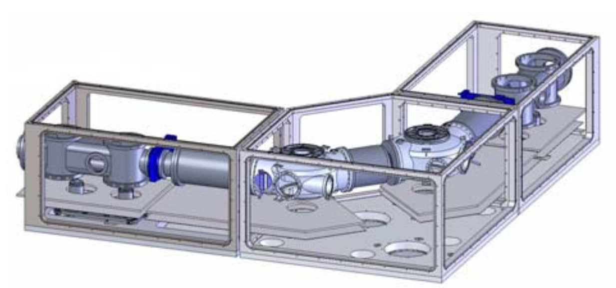

Figure 4: Design drawing of one corner. The frames of the outer chambers and the inner cold chambers are visible. Large rectangular flanges allow easy access.

The chambers for the 39° deflectors have been designed and are already ordered. Due to the helicoflex sealing concept the flanges can now be produced from the same material as the chambers (stainless steel, 1.4435) at considerably lower costs.

Figure 5 presents a model of the designed ion-optic cell showing the quadrupole electrodes. On the left side is an integrated cooling unit. The length of this element is about 50 cm and it will be realized with a rectangular cross section due to space arguments.

OUTLOOK

After the first successful cool down of the prototype the vacuum measurements during the next one will be followed by injection and storage of ions from an external source. As a next milestone the assembly of one complete corner section of the CSR is planned, to test the accuracy achievable with the new support system. To facilitate this, we will leave the inner vacuum system open to the isolation vacuum allowing easy access to the targets inside. Due to the design now chosen the accuracy of the optical alignment will not be influenced by the vacuum. After the successful demonstration of the corner suspension scheme the remaining ring components can be ordered.

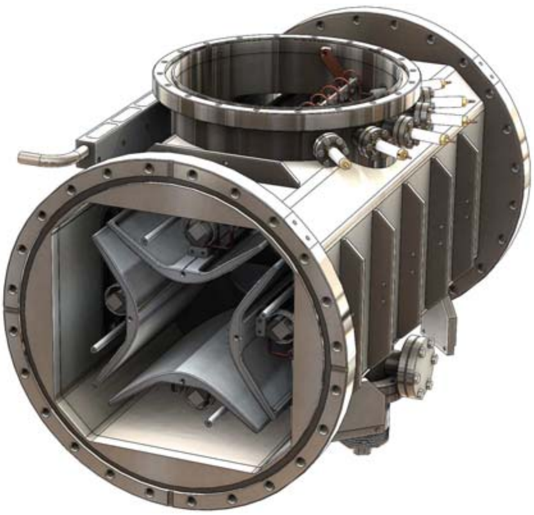

Figure 5: The ion-optic cell with the quadrupole electrodes. On the left the evaporation helium line is visible.

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