DESIGN OF THE DOUBLE ELECTROSTATIC STORAGE RING DESIREE

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Abstract

A double electrostatic storage ring named DESIREE is under construction at the Manne Siegbahn Laboratory and Stockholm University. The two rings will have the same circumference, 9.2 m, and a common straight section for merged beam experiments with ions of opposite charges. The whole structure will be contained in a single vacuum vessel resulting in a very compact design. In addition to its unique double ring structure it will be possible to cool DESIREE below 20 K using cryogenerators. This will reduce the internal vibrational and rotational excitations of stored molecules. A cold system will also result in excellent vacuum conditions where longer lifetimes of the stored beams can be expected. While the ion optical calculations have entered a final phase much of the work is now devoted to solve many of the mechanical and cryogenic challenges of DESIREE. In order to test the mechanical and cryogenic properties of insulators, vacuum seals, and laser viewports a small test system has been built. The test system will provide valuable information for the final design of DESIREE.

INTRODUCTION

The pioneering work of S. P. Møller with the electrostatic storage ring ELISA [1] introduced a new tool for studies of low energy ions in atomic and molecular physics. The use of electrostatic storage rings for low energy ions can be motivated in many ways. Magnets are expensive, big and heavy but with electrostatic elements a compact and less expensive solution can be realized. The fact that all elements are electrostatic means that, for an injector on a given potential, charge and mass of the injected ions can be changed without any need of changing the settings of the optical elements. Another advantage is that an electrostatic ring can handle heavy ions in low charge states, which often is a problem in magnetic rings where maximum mass of the stored ions is limited by the bending power of the magnets.

During the last couple of years the Manne Siegbahn Laboratory in collaboration with Stockholm University is working on the design of an electrostatic storage ring with some unique features. The project is named DESIREE (Double ElectroStatic Ion Ring ExpEriment) [2, 3] and is an electrostatic double ring for merged beam experiments operating at both room and cryogenic temperatures. The latter will offer the possibility to study stored molecular ions in their lowest quantum states. Operating at temperatures below 20 K will also result in a very good vacuum which will increase the lifetime of the stored ions. At room temperature, vacuum pressure has to be in the order of $1\text{x}10^{-11}$ mbar to obtain reasonable lifetimes. In addition to merged beam experiments, DESIREE will be used for single ring experiments.

TECHNICAL DESIGN

Rings and Injectors

DESIREE consists of two rings with one common straight merger section. Each of the rings has two 160º cylindrical bends and four 10º parallel-plate deflectors where the two 10º deflectors on both ends of the merger section are common for the two rings. This means that only ions with opposite charge can be stored in the two rings at the same time. As can be seen in Fig 1 the lower ring (ring 2) has a somewhat different layout compared to the upper ring (ring 1). Ring 2 can store ions with different energy or charge compared to the ring 1 and the bending angle will therefore differ from 10º in the two common deflectors. In order to compensate for that, and to make ions beams run collinear in the merger section, additional deflector plates are added to ring 2. Each ring has four quadrupole doublets for focusing of the beams and a few smaller deflectors for minor corrections of the beam position. Injection of ions into the two rings is done by rapid switching of the respective 10º deflectors.

At least two injectors are planned for DESIRRE, one with a maximum voltage of 25 kV and one mainly used for heavier ions with a maximum voltage of 100 kV. Both injectors will hold an analyzing magnet and different kinds of ion sources.

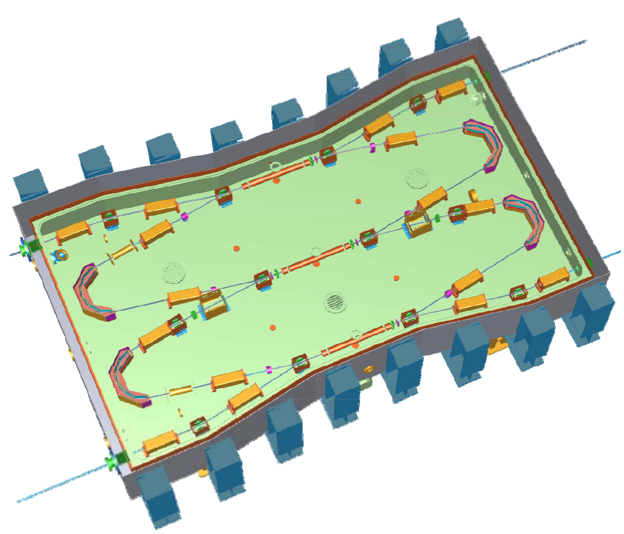

Figure 1: Schematic layout of DESIREE.

In order to reduce the power consumption of the heavy ion platform, the magnet itself will be on earth potential while its vacuum chamber will be insulated for 100 kV. It will be possible to inject ions from each of the injectors into both rings. Several types of ion sources will to be used on the platforms. In addition to typical plasma sources for singly charged atomic and molecular ions there will be an expansion source for producing rotationally cold molecular ions, an electrospray source for biomolecules, and a sputter source for generating negative ions. The electrospray source has recently been constructed and initial test have started.

Ion Optics

A complete presentation of the beam calculations is beyond the scope of this paper. Instead some important observations will be presented here. From calculations with COSY [4] and SIMION [5] areas with stable orbits with respect to quadrupole settings have been established for both rings. Ongoing calculations on the most critical elements show that these stable areas can be increased if the shapes of the elements are optimized.

Fast Noise

In order to find out how stable the supplies for the optical elements have to be, several simulations and some measurements have been performed. Static supplies can be equipped with filters to avoid fast noise, but the situation is more difficult for the injection supply. It has to switch from -10º to +10º in less than a µs and then be stable as long as the beam is stored. The fast switching time excludes the same solution as for static elements.

If the beam fills the acceptance both fast (faster than the revolution frequency) and slow noise reduces the beam intensity, but if the beam is smaller than the acceptance slow noise only moves the beam, while fast noise causes diffusion and emittance growths until the acceptance is filled and one starts to loose beam.

A simple tracking program has been used to study the influence on the emittence. Simulations with high-frequency noise has given the following estimate of emittance growth.

$$\Delta\varepsilon_x = 22000 N\beta_x \frac{\Delta U}{U}$$

$\Delta\varepsilon_x$ is the growth of the horizontal emittance in π mm mrad, N is the number of turns ($0.3\text{-}3\times10^6$ for 10 keV ions with mass 1000-10 stored for 60 s), and β_x is the horizontal beta-function. $\Delta U/U$ is the fast noise on the 10º injection bend, defined so that the absolute noise is below ΔU 95% of the time. From the simulations it follows that in order to be able to store a beam with an emittance growth of maximum 1 π mm mrad for 60 s, the noise $\Delta U/U$ should not be larger than 1×10^{-6}. This is not easy to achieve. Measuring the same effect from noise on one pair of kickers on a 40 keV Ne^+ beam stored in the magnetic storage ring CRYRING indicates that the beam

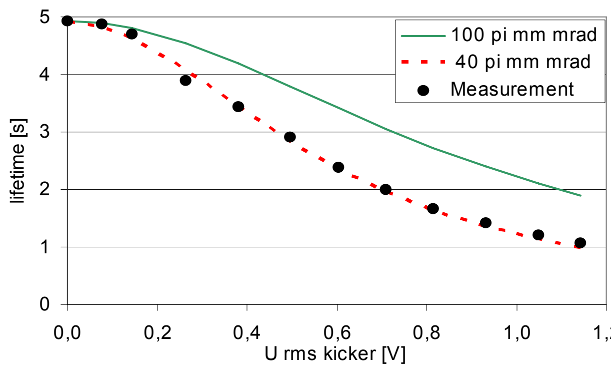

Figure 2: Lifetime dependence of the kicker amplitude. Comparison between measurement and simulations with two different acceptances.

is even more sensitive than the simulations shows since the acceptance in CRYRING normally is larger than 40 π mm mrad (Fig. 2). There are however some uncertainties in the measurement which have to be investigated before any final conclusion can be made.

Mechanical Design

The two rings will be housed in a common double-walled vacuum chamber where the outer chamber will be built from steel. The external dimensions of the outermost chamber will approximately be 5.0 m x 2.0 m x 0.7 m. In order to stand the pressure difference it will be reinforced with an external framework of beams on all sides. The inner chamber will, for vacuum technical reasons, be made from aluminium. All optical elements and detectors will be mounted directly on the bottom of this chamber. Between the two vessels there will be a thermal screen and between the screen and the outer chamber several layers of super insulation will be added. All components like pumps, cryogenerators and electrical feedthroughs will be mounted on the bottom of the vessels in order to facilitate access to the two vessels from the top.

DESIREE will be operated both at room and at cryogenic temperatures. During cold mode operation the inner chamber will be cooled with two cryogenerators (Sumitomo RDK-415D) where the first stage of the cryogenerators will be connected to the screen and the second to the bottom of the aluminium chamber. It is estimated that the total heat load on the thermal screen and the inner vessel will be 60 W and 3 W, respectively. The main contribution to the heat load on the inner vessel is blackbody radiation from the screen. If this low heat load can be realized, the final temperature of the inner vessel and the rings should be around 5 K. If necessary, it will be possible to add two additional cryogenerators.

At cryogenic temperatures the inner vessel will be pumped by the cold walls of the chamber. The main contribution to the background pressure will be H_2 which will be reduced by Ti sublimation pumps. At room temperature, the inner chamber will be pumped with a combination of high compression turbo pumps and Ti sublimation pumps. After baking at 150º C of the aluminium vessel, a pressure of 1×10^{-11} mbar is expected.

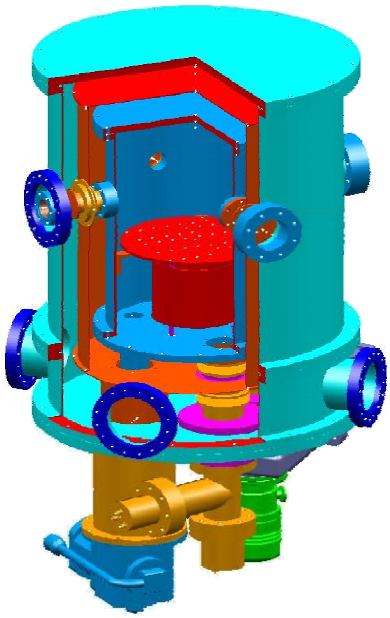

Figure 3: Schematic drawing of the test system with the outer chamber (light blue) inner aluminium chamber (blue) and thermal copper screen (red).

to be reached at room temperature. The outer chamber, whose main purpose is to thermally insulate the inner vessel, will be pumped with turbo pumps.

TEST SYSTEM

In order to meet the technical challenge of designing a system like DESIREE it was soon realised that a smaller test and training system has to be built. Among the things that will be tested are mounting of the cryogenerator and laser windows as well as the cryogenic and vacuum properties of different materials, vacuum gaskets and other components where data are hard to find or lacking.

The test chamber (Fig. 3) is built as a cryostat with an inner and outer chamber and a copper screen in between. The outer chamber is made from stainless steel while the inner chamber is made from aluminium. No super insulation is initially used in the test set-up. In order to minimize the heat conductance between the two vessels, the inner chamber is only resting on three thin walled stainless steel tubes on the bottom of the outer chamber. The test chamber is pumped with two turbo pumps, one for each chamber. In addition, the inner chamber holds a Ti sublimation pump. When operating the system at cryogenic temperatures, the turbo pump connected to the inner vessel is sealed off and vacuum is maintained by the cold chamber walls together with the sublimation pump. The system is equipped with a residual gas analyzer (RGA) for analyzes of the background gas. All components communicating with the inner vessel, like turbo pump, pressure gauge, RGA and electrical feedthroughs are mounted on the bottom of the outer vessel. The turbo pump and RGA are interfaced with the inner chamber via thin walled bellows with cooled baffles in order to minimize the heat load on the inner chamber. All flanges on the inner chamber are sealed with Helicoflex gaskets. On the outer chamber, where the vacuum requirements are not that high, o-rings are used.

Cooling is achieved by a two stage cryogenerator (Sumitomo RDK-415D) with a specified cooling capacity of 35 W at 50 K on the first stage and 1.5 W at 4.2 K on the second stage. The first stage is connected to the copper screen and the second to the bottom of the aluminium vessel via a flexible copper braid. In order to test the cooling, temperature sensors are mounted on the aluminium chamber and the screen. Before mounting the cryogenerator on the test set-up, tests were performed to verify its specified cooling power and to measure cooling power at temperatures where it is not specified. The results agreed with the ones stated by the manufacturer.

The test set-up has been under vacuum for some time and initial cooling tests have been performed. During these tests the aluminium chamber bottom reached 9 K while the second stage of the cryogenertor was at 4.5 K. From the cooling power test it can be concluded that the total heat load on the aluminium chamber is 1.5 W. The somewhat higher temperature observed at the inner vessel is due to the limited thermal conductivity of the flexible copper braid. There are, however, several improvements that can be done to lower the heat load and improve the thermal conductivity.

Another important task for this set-up will be to test the cryogenic properties different kinds of detectors that are planned to be used in DESIREE. The first detector to be tested is a microchannel plate (MCP). The properties of MCPs change rapidly with temperature and at cryogenic temperatures very little data exist [6]. Finally, there is an interest of using the test set-up for experiments not related to DESIREE. One specific example is experiments with ions stored in the electrostatic ConeTrap [7]. This trap is ideal for life time determination of the metastable helium anion, $He^-(1s2s2p\ ^4P_{5/2})$. Results of earlier measurements of this lifetime have been limited in accuracy of the systematic effect caused by the photodetachment of the loosely bound 2p electron by photons of the 300 K blackbody radiation from the surrounding vacuum chamber. By performing this experiment in a cryogenic environment, this effect is essentially eliminated.

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