DESIREE – A DOUBLE ELECTROSTATIC STORAGE RING

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Abstract

DESIREE is a double electrostatic storage ring being built at the Manne Siegbahn Laboratory and Stockholm University. It will consist of two 9.2-m-circumference rings with one common straight section, and the rings will be built in a single large vacuum vessel that can be cooled to cryogenic temperatures. The project was funded through grants in 2003 and 2004, and commissioning is foreseen for 2007. DESIREE will be used for experiments in atomic, molecular and optical physics as well as biophysics and biochemistry.

INTRODUCTION

The use of electrostatic storage rings in atomic, molecular or optical physics was initiated by S. P. Møller with the ELISA storage ring [1]. This is a small ring with 6.28 m circumference that has been in operation since 1998. A similar ring was later built by T. Tanabe *et al.* [2].

Electrostatic storage rings for low-energy ions have several advantages compared to magnetic storage rings. The most important one is probably cost. Small electrostatic beam-optical elements are considerably less expensive than magnets. The cost benefit becomes even more pronounced when the ring is to be cooled to cryogenic temperatures. Another advantage of an electrostatic ring is the fact that, if ions are injected from a platform at a constant voltage, the settings of the ring remain independent of ion mass. In a magnetic ring, very heavy ions will be very slow, which can be a difficulty for experiments when it comes to, e.g., detection of reaction products.

The DESIREE (Double ElectroStatic Ion Ring ExpEriment) project has two rings, each of which has a layout similar to ELISA. The rings are placed in a common vacuum vessel, and they have one common straight section for the study of ion–ion collisions. The vacuum vessel is built as a cryostat with double walls, allowing the rings to be cooled down to around 10 K or less. This will make it possible to store, for instance, molecular ions in their lowest quantum states, emulating conditions in cold environments such as interstellar plasmas. The low temperature also gives a very good vacuum, which is important for the storage lifetime of the ions. It should also be possible to operate the rings up to room temperature, requiring that the whole system be bakable. The ions will be injected into the two rings from external ion sources on two separate high-voltage platforms.

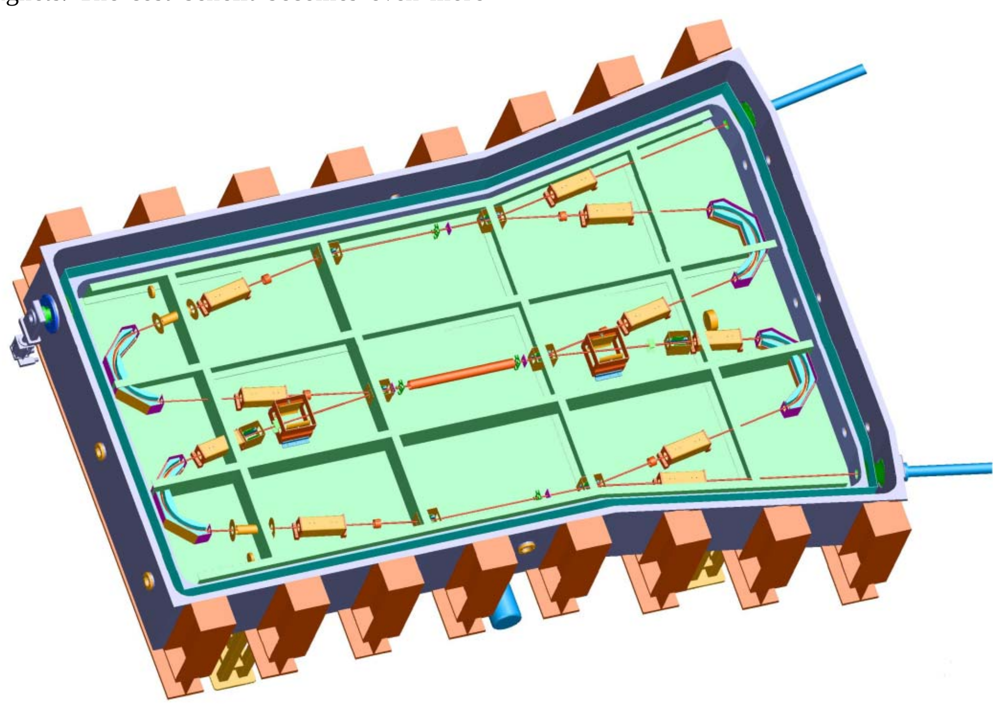

Fig.1. Schematic layout of DESIREE with the lids of the vacuum vessels off. The outer dimensions are approximately 5×3×1 m.

TECHNICAL DESIGN

Rings

The rings have an oval shape with two 160-degree bends and cylindrical bending plates. Additional 10-degree deflections are used for injection and for merging and separating the beams in the common straight section, and they give a free line of sight along the straight sections. The length of the straight sections is determined mainly by the wish to have a reasonably long overlap between the two beams, and also with external beams of laser light. The layout of the rings is shown in fig. 1.

The design is made for a maximum voltage of 100 kV on the injector platforms. For reasons of space and cost, however, only one of the platforms will be designed for 100 kV while the other platform will be designed for 25 kV. It is foreseen to inject ions with platform voltages down to 5 kV or less.

The use of DESIREE for merged-beam ion–ion collision studies close to zero relative energy constrains the relation between ion charge-to-mass ratios and beam energies in the two rings, and these, in turn, define the geometry of the deflection plates around the common straight section. The design has been chosen such that ions leaving the common section must deflect in opposite directions in the first pair of deflection plates, implying that merged-beam experiments can be performed only if one ion is positively charged and the other one negatively charged. Ions in the lower ring in fig. 1 (ring 2) then pass two more pairs of deflection plates in order to get onto the right orbit. The apertures between the plates are such that the ratio of deflection angles (i.e., the ratio of ion energies per unit charge) between the two beams can range between 1 and 20. The ion that deflects by the smallest angle, normally the heavier ion, is stored in ring 2, which is also the one supplied by the 100-kV platform.

Injectors

The 100-kV platform will, apart from the ion source, hold an analyzing magnet. The magnet will have a bending power of approximately 2 Tm, implying a maximum atomic weight for singly charged ions of 100 kDa with 2 kV from the ion source. The typical resolving power will be about 1000 but depends on the emittance and energy spread from the ion source. The 25-kV injector is foreseen to have a smaller analyzing magnet in order to save costs. However, it will be possible to inject ions from one ring to the other, giving maximum flexibility in the choice of ions and ion sources.

Different kinds of ion sources can be mounted on the platforms. In addition to standard Nielsen-type sources for singly charged atomic and molecular ions, the project includes a sputter ion source for negative ions, an electrospray source for biomolecules and a small ECR source.

Mechanical Design

The two rings will be housed in a single double-walled vacuum vessel, acting as a cryostat, with external dimensions of approximately 5×3×1 m. Both vessels will be made from aluminium in order to save weight and to allow a low bakeout temperature for the ultra-high vacuum needed for the ion storage lifetime. The outer vessel will support the atmospheric pressure whereas the inner vessel can be made from much thinner material. Both vessels will have single lids almost as large as the vessels themselves. Feedthroughs will be mounted on the bottom of the vessels such that the lids can be opened without disconnecting the feedthroughs. The ion-optical elements will, for reasons of thermal conductivity as explained below, be built on a plate of copper or aluminium inside the inner vessel.

The stiffness of the whole structure as well as thermal shrinkage will considered carefully since the alignment of the optical elements must be maintained as the vessels are evacuated and cooled down.

Cryogenics

The inner vessel will be cooled to cryogenic temperatures using cryogenerators. It is estimated that one can reach 10 K or possibly even lower with cryogenerators that, according to specifications, have cooling powers of 10 W at 8 K or 2 W at 5 K at the second stage at the same time as the first stage absorbs 65 W at 70 K. The first stage will be connected to a screen which is separated from the outer vessel by some 30 sheets of superinsulation. Superinsulation is not needed between the 70-K screen and the inner vessel.

As it should be possible to use the temperature as a parameter in physics experiments, it will be possible to operate the rings at all temperatures from room temperature and down to 10 K or less. This requires that the inner vessel is bakable to around 150°C. In order to protect the superinsulation, the screen between the two vessels will be cooled during the bakeout. The cryogenerators will have to be disconnected during bakeout.

It is estimated that the time required for cooldown, using only the cryogenerators, will be approximately three days. Here, it is important that the thermal coupling between the cryogenerators and all elements inside the inner vessel is very good. For this reason, the ion-optical elements, detectors, etc., will be mounted on a plate of aluminium or high-conductivity copper. The time for cooldown can be shortened if the inner vessel is provided with tubes through which liquid nitrogen can be poured.

It is essential that the heat leakage through viewports, electrical feedthroughs, etc., is kept at a minimum. In particular, the internal temperature of the stored ions will be limited by the amount of warm (i.e., room temperature) surfaces they can see.

Vacuum

At temperatures below 18 K the vapour pressure of all gases except hydrogen and helium is less than 1×10^{-13} mbar. The hydrogen will be pumped by titanium sublimation pumps that have good pumping speeds also at low temperatures, whereas helium can be removed by a high-compression turbo pump if it would turn out to be necessary.

Also at higher temperatures, up to room temperature, the inner vessel needs to be at ultra-high vacuum. This requires, as already mentioned, bakeout to 150°C. Since the surface of the inner vessel is quite large and not easily accessible, the main challenge here is to get sufficient pumping capacity. With rather large titanium sublimation pumps we nevertheless estimate that a pressure of 5×10^{-12} mbar can be reached.

Ion Optics

Both rings have two cylindrical 160° bends and four 10° deflectors, which is similar to the layout of ELISA. In the long straight sections, there will be cylindrical drift tubes surrounding the beam which will allow scanning of collision energies, application of Doppler-tuned laser spectroscopy, etc. Four quadrupole doublets in each ring give vertical focusing, while the bends and deflectors give additional focusing in the horizontal plane. Also the drift tube will contribute some focusing in both planes.

The two rings are somewhat different in that ring 1 has two symmetry planes whereas ring 2 only has one because of the arrangement with the four additional pairs of deflection plates and the focusing in these plates.

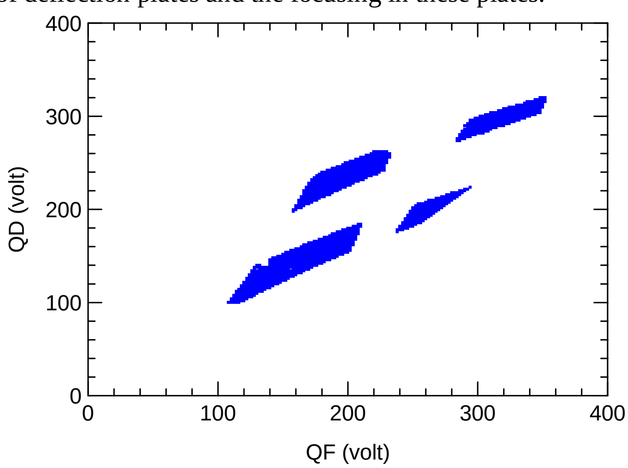

Fig. 2. Areas of stable motion in ring 1 as a function of the two quadrupole voltages, assuming 10 keV ions.

The optics of the rings was first calculated using COSY INFINITY [3]. This code can perform calculations on electrostatic elements, including cylindrical bends and quadrupoles with end effects. It does not accept deflectors with plane electrodes, but these were approximated with cylindrical deflectors for the calculations. Based on the results from COSY, tracking calculations were performed with SIMION [4], which solves the electrical fields in all elements numerically, and thus gives a more exact result, but takes much longer time to run. The agreement between the two methods was found to be very good.

Fig. 2 shows a stability diagram for ring 1 calculated with SIMION. The stable areas are plotted as a function of voltages on focusing and defocusing quadrupoles. Ring 2 has only one symmetry plane, so the quadrupole voltages in the upper half of the ring can differ from those in the lower half. The stable areas are also a bit smaller since the quadrupoles are further apart in the upper half.

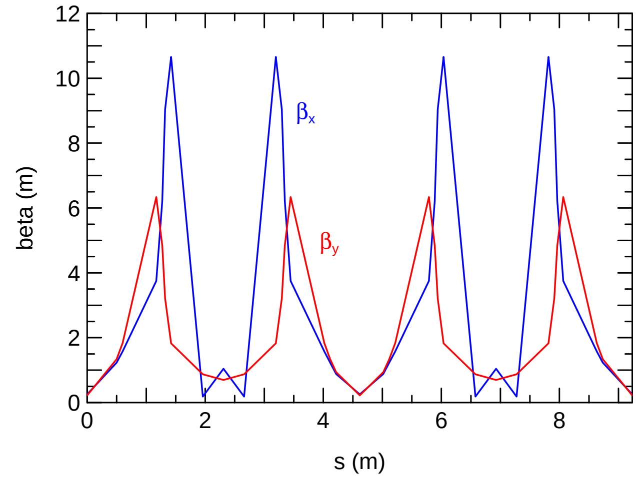

Fig. 3. Example of beta functions in ring 1 at a working point where the beam has a focus in the straight sections.

Fig. 2 was calculated with realistic betatron amplitudes but zero energy spread. Electrostatic quadrupoles have larger aberrations than magnetic quadrupoles, due to the fact that ions that do not move on the optical axis change velocity in the electrical fields, making non-linear effects important for particles with large amplitudes. The size of the stable areas thus depends significantly on the beam emittance.

APPLICATIONS

The most important unique feature of DESIREE is the possibility to perform merged-beam experiments with positive and negative ions that are stored at low temperatures. Examples of research using these features include mutual neutralization in fundamental atomic and molecular systems, in astrophysical plasmas and in atmospheric ion chemistry, studies of processes similar to electron capture dissociation of molecules and the physics of biomolecules after electron capture. The experimental geometry further allows for merged-beams experiment with a stored beam of positive ions and a single-pass neutral beam produced from anions by laser photodetachment.

Using only one ring, DESIREE also offers new possibilities through its cold environment and good vacuum together with the absence of magnetic fields. These conditions are ideal for measurements of lifetimes of metastable negative ions as well as for metastable states of positive ions. For larger systems such as fullerenes and biomolecules the lifetime and detailed spectroscopy in general become temperature dependent and with its low temperature DESIREE will open a new regime for such studies.

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