LAYOUT OF AN ELECTROSTATIC STORAGE RING AT KACST

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Abstract

A state-of-the-art fixed energy electrostatic storage ring that will allow for precision experiments with most different kinds of ions in the energy range of up to 30 keV will be constructed and operated at the National Centre for Mathematic and Physics (NCMP) at the King Abdulaziz City for Science and Technology (KACST). The ring is planed to be the central machine of a unique and highly flexible experimental platform. The lattice design therefore has to cover the different experimental techniques that the ring will be equipped with, such as e.g. electron-ion crossed-beams and ion-laser/ion-ion/ion-neutral merged-beams techniques. This paper presents the technical and particle optical design of this novel machine, explains the particular challenges in its layout, and reports on the general project status.

INTRODUCTION

Electrostatic storage rings have proven to be invaluable tools for studies in atomic physics and biophysics, i.e. for life sciences in general. Around some tens of keV, they allow storing ions irrespective of their atomic mass and avoid problems related to hysteresis effects and the remanence that would be encountered in magnetic storage rings at comparably low energies.

Despite their distinct advantages for fundamental research in the low energy regime, only three such machines are in operation around the world, all of them having a comparable, compact racetrack-shape layout and working at a fixed energy of 20 keV [1, 2] or 30 keV [3] with a continuous beam. Two of the rings [1, 3] can be operated at liquid nitrogen temperature and only one of them [2] is equipped with an electron merged beam device, which works at the required low energies but with a rather limited resolution. A double electrostatic ring, operating in a merged beam configuration and at temperatures below 10 K, is presently being built at MSL in Stockholm [4], a fixed energy storage ring for energies up to 50 keV was designed and assembled at the University of Frankfurt [5], a cryogenic storage ring (CSR) is planned at the Max Planck Institute for Nuclear Physics [6], and an ultra-low energy storage ring will form a central part of the future facility for low energy antiproton and ion research [7], [8].

In addition to the above mentioned storage rings, a new state-of-the-art fixed energy machine for beam energies of up to 30 keV is presently being developed at KACST [9] and will serve as the central experimental and training platform at NCMP in the near future.

STORAGE RING LAYOUT

The storage ring at KACST shall finally act as a true multi-purpose and multi-user machine, allowing for experiments with different kinds of ions, such as Protons or Oxygen, but also with heavy biomolecules that would then be provided by an electrospray ion source via the injector complex [10,11]. This requires a careful optimization of the overall ring layout to these different scenarios.

Racetrack Layout

A very compact geometry was investigated as a possible “starting scenario”, Fig. 1. In this configuration, the beam is injected along one of the machine’s straight sections into one of the 7° parallel plate deflectors that would be switched off during the injection process. The modulation of the beam is realized by pairs of electrostatic quadrupoles as described in detail in [11]. The main bending of the beam is done by two electrostatic 166° cylinder deflectors.

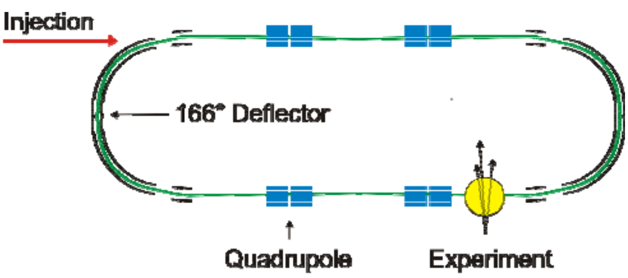

Figure 1: Racetrack layout of the storage ring, consisting of one 166° cylinder deflector and two 7° deflectors.

The storage ring has a circumference of roughly 8.4 m. The machine can be set to different operating modes with one example shown in Fig. 2.

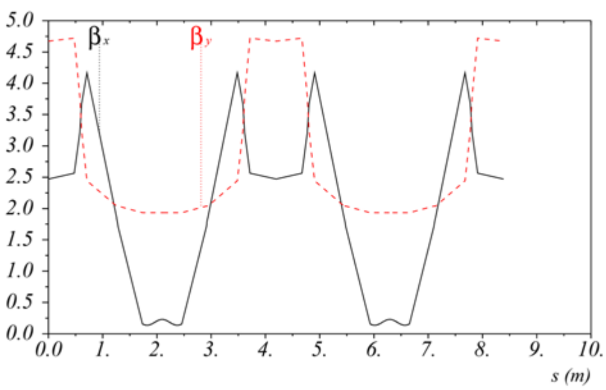

Figure 2: Lattice function as calculated with MAD.

Experiments can be done either in the central region of the long straight sections or in between the quadrupoles and the deflectors which would allow detecting even strongly divergent particles at the end of the straights. A vertical steerer (not shown in fig. 1) will be used for closed-orbit correction. The beam diagnostic elements consisting of electrostatic pickups, beam viewers and Faraday cups will be placed within the experimental zones and partially between the deflectors.

The following table 1 summarizes the machine parameters.

Table 1: Parameter of the racetrack storage ring.

Parameter	Value
Maximum beam energy [keV]	30
Injection	Single turn
Space charge limit	$2 \cdot 10^7$
Beam life time [s]	10
Vacuum pressure [mbar]	10^{-11}
Machine circumference [mm]	8387
$\beta_{x,max}$ [mm]	4167
$\beta_{y,max}$ [mm]	4721
Q_x	2.353
Q_y	0.411
D_{max} *[mm]*	515

Split-deflector Layout

A central idea of the project from the beginning has been the possibility of extending the experimental setup to a double ring structure, where merged and colliding beam experiments can be realized, but where also the large circumference of the entire double ring can be used to avoid/minimize e.g. space charge induced tune shift and thus increase the max. beam current in the machine.

Such an extension is only possible, if a layout as shown in Fig. 3 is chosen. In this case injection is done along one of the short sections of the machine, thus avoiding the problem of neutral particles coming from the injection channel hitting the detectors behind the experimental zone. This compact machine consists of four 76° cylinder deflectors with a mean radius of 250 mm and a plate distance of 30 mm. A gap of 200 mm is left between the two quadrupoles installed in the machine's short side. This space could then be used to integrate e.g. a compact electron target. All other machine components are identical to the ones presented above. With a slightly increased circumference of 11.16 m this machine offers much more possibilities for internal experiments being installed at the same time and also a future extension to a double ring structure where the entire machine would be built up a second time and coupled with this existing structure seems feasible.

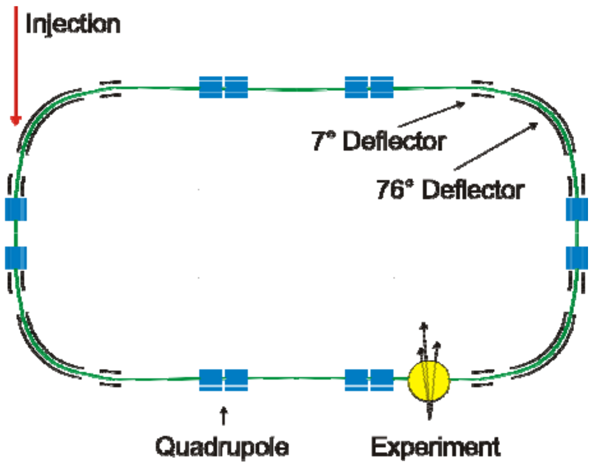

Figure 3: Split-deflector layout of the storage ring.

Fig. 4 shows the lattice configuration at a working point where Q_x*=2.51* and Q_y*=0.27*. The maximum beta function is around 20 m in the x- and 16 m in the y direction and thus considerably larger than for the racetrack-shaped machine.

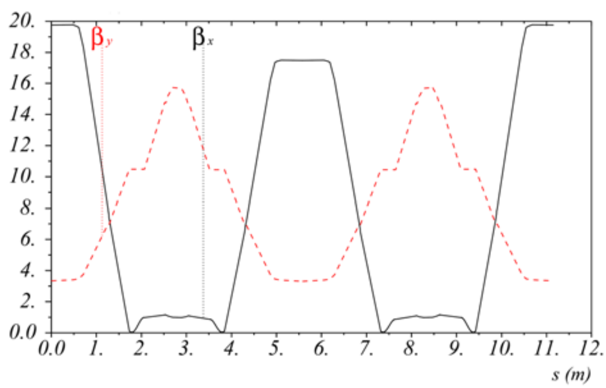

Figure 4: Lattice functions for the split-deflector layout as calculated with MAD.

OPTICAL ELEMENTS

Both storage ring configuration use only electrostatic elements for beam bending and focusing. Due to the mass-independence of the electrostatic rigidity this allows for storing a light ion, like e.g. a proton in the same field configuration as a singly charge biomolecules with a very high molecular mass.

Beam bending is mainly realized by electrostatic cylinder deflectors with a central radius of 250 mm and a plate distance of 30 mm. The height of each electrode is 100 mm. Grounded shields at the entrance and exit regions as well as on top of and below the electrodes effectively reduce the influence of fringe fields on the stored beam.

In case of the split-deflector geometry a 7° parallel plate deflector as shown in Fig. 5 complements the ion optical elements. Due to the relatively small deflection angle, the difference in the action on the beam between a cylinder deflector and a parallel plate deflector is very small. The support structure of this element follows the design chosen for the quadrupole doublets [11]. The plates cover a surface of 100 mm x 100 mm and are located 50 mm apart from each other. Circular disks made of stainless steel act as grounded shields and for removing divergent particles from the beam before they can hit the electrode surfaces. Voltages are applied in a symmetric way to the electrodes and are below ±5 kV.

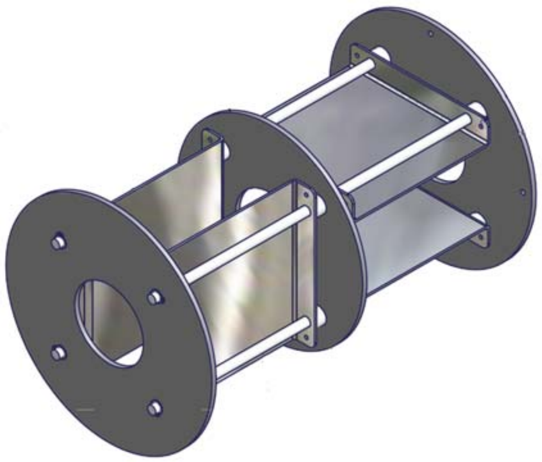

Figure 5: Mechanical design of the electrostatic 7° deflector and the vertical steerer.

One of these deflectors will be connected to a fast voltage switch and be used during beam injection.

Horizontal and transverse modulation of the beam is realized by electrostatic quadrupole doublets. Each quadrupole electrode has a length of 100 mm. Their mechanical aperture is $r_{ap}=25\ mm$ and the radius of curvature of the electrodes is $r=1.148 \cdot r_{ap}=28.7\ mm$. The electrodes are supported by Aluminum oxide rods and put in position by Macor spacers. All quadrupoles will be assembled and aligned outside of the vacuum chamber.

CONCLUSION AND OUTLOOK

In this contribution, the design of a fixed energy electrostatic storage ring for beam energies up to 30 keV was presented. The machine will serve as a multi-user, multi-purpose experimental facility at the NCMP/KACST which will give rise to cutting edge research in both atomic physics and accelerator sciences. It will furthermore allow for an efficient training of young researchers in all fields concerned. A possible option of extending the experimental possibilities even further by adding a second storage for merged and colliding beam experiments was briefly discussed. Future studies include an in-detail investigation of the beam motion, in particular of non-linear dynamics and space charge effects, as well as the study of the available dynamic aperture.

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