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Layout of a Novel Electrostatic Storage Ring at KACST

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The aim of the Pro-ESR project is to design, construct and operate 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 at the National Center 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 experimental platform that will allow, for the first time, to combine storage-ring and single-pass experiments. The lattice design therefore needs to take the different experimental techniques that the ring will be equipped with into account, such as e.g. electron-ion crossed-beams and ion-laser/ion-ion/ion-neutral merged-beams techniques. Others kinds of experiments that will be connected to the ring will be dedicated to material and surface sciences, like e.g. ion sputtering and ion beam analysis and characterization (IBA), which require a high quality of the optical scheme.

This paper presents the technical and particle optical design of this novel machine, explains the particular changes in its layout, and reports on the general project status.

Keywords: Storage ring, electrostatic fields, atomic physics, collision studies, beam dynamics.

1 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

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allow avoiding problems related to hysteresis effects and the remanence of magnetic fields. Today only three such machines exist in 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].

As compared to magnetic storage rings, electrostatic machines have the clear advantage of the mass-independence of the electrostatic rigidity, i.e. the fields depend on the beam energy and ion charge only, irrespective of the ion's mass. This allows for operating such a storage ring with most different ion species and thus gives access to a wide physics program.

2 Storage Ring Layout

The Pro-ESR 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. Thus a careful optimization of the overall ring layout to these different scenarios is required. The machine needs to be designed for a high quality low-energy beam with high-luminosity, small emittance, guaranteering (at least) several seconds of beam lifetime, and small momentum spread to allow for high resolution measurements, and has to be flexbile enough to allow for an integration of additional beam lines. In its final stage the storage ring shall serve different scientific communities and shall be used at the same time as an experimental and a training facility.

The proposed storage ring features a racetrack-like scheme with two long and two short sections, which allows for integrating several internal experiments while keeping the overall storage ring dimensions reasonably small. The general parameters of the storage ring are summarized in Table 2.1.

2.1 Cylinder deflectors

The beam bending in the corner section of the storage ring is realized by means of electrostatic cylinder deflectors. A split geometry consisting of two 7° deflectors and a

Table 2.1: General parameters of the Pro-ESR at 30 keV

Energy	30 keV
Circumference [m]	20.42
Cell length [m]	10.21
Length drift space 1 [m]	1.3
Length drift space 2 [m]	0.5
Injection	Single turn
Beam life time [s]	10
Vacuum pressure [mbar]	10^{-11}
Space charge limit	$2{\cdot}10^{7}$

central 76° deflector was chosen. This gives on the one hand the possibility for injection into the ring without the use of a dedicated injection septum. On the other hand it is possible for neutral atoms, created in an experiment along one of the straight sections, to reach a detector which is placed outside of the ring. The general parameters of the cylinder deflectors are summarized in Table 2.2

Table 2.2: General Parameters of the Cylinder Deflectors

Length 76^o deflector [m]	1.326
Length 7^o deflector [m]	0.12
Radius 76^o deflector [m]	1.0
Radius 7^o deflector [m]	0.9
Plate distance [m]	0.06
Voltages [kV]	±6

A central drift space of $l = 1.3$ m is located between the quadrupole doublets and is mainly reserved for experiments and beam diagnostics equipment. The second drift space, located in the adjunct quarter of the ring has a total length of $l = 0.5$ m. This space is kept as a possible future experimental section, located closer to the deflector exits. A third experimental section is provided by an additional drift space of $l = 0.523$ m, located between the quadrupole and the 7° deflector, which allows for positioning the experiment close to the corner section and thus for maximizing the solid angle for the detection of neutral particles created in in-ring experiments. Finally, the drift space between the 7° and the 76° deflectors is a result of an optimization process regarding simple injection of the particles into the ring and efficient detection of neutral particles.

Table 2.3: General Parameters of the Electrostatic Quadrupoles

Length [m]	0.1
Distance to shield [m]	0.01
Shield thickness [m]	0.003
Aperture radius [m]	0.025
Voltages [kV]	±3

2.2 Electrostatic quadrupoles

The modulation of the transverse beam dimensions is realized by four electrostatic quadrupole doublets and two dedicated pairs of focusing quadrupoles in the straight sections. This combination allows to obtain an almost round beam in the centre of each straight section, while keeping the beam size small in the corner sections as well. Following the results in [9] the quadrupoles are surrounded by grounded shields on both sides to reduce the influence of fringe field effects on the stored ion beam. The quadrupole parameters are summarized in Table 2.3

2.3 Lattice design

The lattice presented above was simulated using the lattice code MAD-X [10]. Thereby a proton beam with a kinetic energy of $T = 30$ keV was assumed, reflecting the injector conditions currently under design [11, 12]. The linear lattice functions are shown in Figure 2.1 and Figure 2.2.

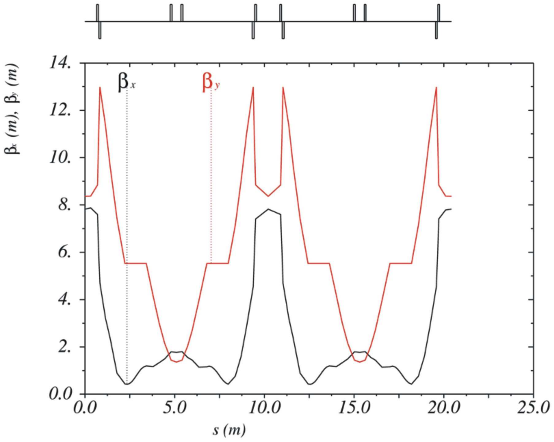

Figure 2.1: Lattice functions as calculated with MAD-X.

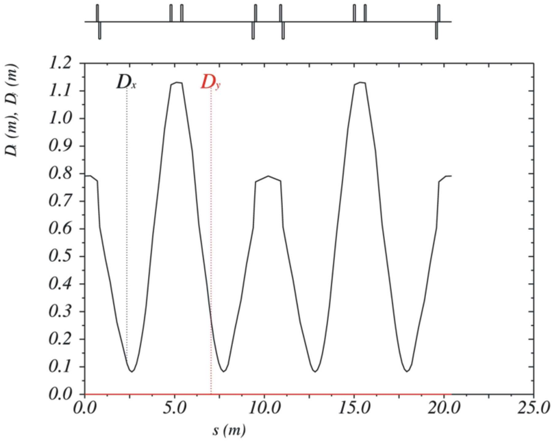

Figure 2.2: Dispersion functions as calculated with MAD-X.

Starting with the initial settings for the simulation a closed-orbit solution was searched first, while a matching routine was used afterwards to achieve the small $\beta_{x;y}$ functions shown. With the present quadrupole settings a round beam is possible in the straight sections as desired for the experiments. It should also be mentioned that the β_x function is even smaller in the bending sections as compared to the long drift spaces. This indicates a focused beam in the corners. The larger β_y function will not be of any concern, as the cylindrical deflector acts essentially as a drift space in the vertical dimension in which there are no spatial restrictions. The resulting dispersion function as shown in Figure 2.2 is relatively small, with values always below 1.3 m. The following Table 2.4 summarizes the most important TWISS parameters of the Pro-ESR.

Table 2.4: TWISS Parameters of the Pro-ESR Lattice

Q_x	2.8107
Q_y	0.60884
ξ_x	-2.17
ξ_y	-2.1
$\beta_{x,max}$ [m]	7.98
$\beta_{y,max}$ [m]	13.2
$D_{x,max}$ [m]	1.13
γ_{trans}	1.962

3 Outlook: Double Ring Option

A unique feature of the Pro-ESR that has been considered since the beginning in its design, is the possibility to place two of the above-described rings next to another and to combine them into a large storage ring. Thereby several beam operations would become possible: One operational scheme would allow for making use of a larger storage ring, thus opening up the possibility for storing higher beam currents due to a reduced Lasslet tune shift. Another operational scheme would be the independent operation of both rings with two different ion species stored at the same time and thus the possibility of merged or colliding beam experiments. Such an extension to a double-ring scheme requires, however, the full simulation of the lattice of both rings from the beginning. The optical scheme of this storage rings follows as much as possible the lattice presented above so that the racetrack-shaped ring can be used as a base. In order to guarantee maximum flexibility with respect to experiments and easy operation, a four fold symmetry was chosen, resulting in a double symmetric storage ring. The circumference of the large storage ring would be 43.3 m, with a cell length of $l = 10.82$.

4 Conclusion

In collaboration between KACST, the Max Planck Institute for Nuclear Physics, the Cockcroft Institute of Accelerator Science and Technology and the University of Liverpool, the design of a novel fixed-energy electrostatic storage ring was worked out. The machine shall 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 possiblities even further was also presented. Future studies include an in-detail investigation of the beam motion, in particular the non-linear dynamics and space charge effects, as well as the question of the available dynamics aperture, which can only be obtained by real-field simulations and particle tracking.

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