Hyperfine Interactions **146/147:** 253–258, 2003.

Design Studies of an Electrostatic Storage Ring

CARSTEN P. WELSCH[1], ALWIN SCHEMPP[1] and
HORST SCHMIDT-BÖCKING[2]
[1]*Institut für Angewandte Physik, Johann Wolfgang Goethe Universität, Frankfurt am Main, Germany; e-mail: c.welsch@iap.uni-frankfurt.de*
[2]*Institut für Kernphysik, Johann Wolfgang Goethe Universität, Frankfurt am Main, Germany*

Abstract. The design of a small electrostatic storage ring for all different kinds of ions at energies up to 50 keV is presented in this paper. One quarter of such a ring is presently being build up at IAP to study injection, optimize the optical elements and integrate the diagnostic system.

1. Project description

1.1. GENERAL

In the last decades, many activities in the field of accelerator physics have focused on the development of machines with higher and higher final energy. The enormous amount of money needed to finance these projects set a limit to new ideas. As a result, more and more experiments nowadays point into more exact measurements in energy regions of some keV to MeV.

In order to extend possibilities to the fields of decay processes, beam interaction and storage of large biomolecules, the design of a small electrostatic storage ring for ions with energies up to 50 keV was proposed [1, 2].

Such a device may be seen as a cross between an electromagnetic trap and "classical" rings.

Low costs, small size, combined with energy independence of the necessary fields and good accessibility of the experimental sections are only some of the interesting properties. Possible experiments with such a machine cover a wide range: Especially the advantage of being able to store heavy biomolecules for an extended period of time and the absence of magnetic fields make experiments possible one cannot cover with magnetic rings.

In principle, the geometrical shape of an electrostatic machine is not limited by any rules. However, beam energy, aperture and required space for later experiments do reduce the number of possible layouts to a few.

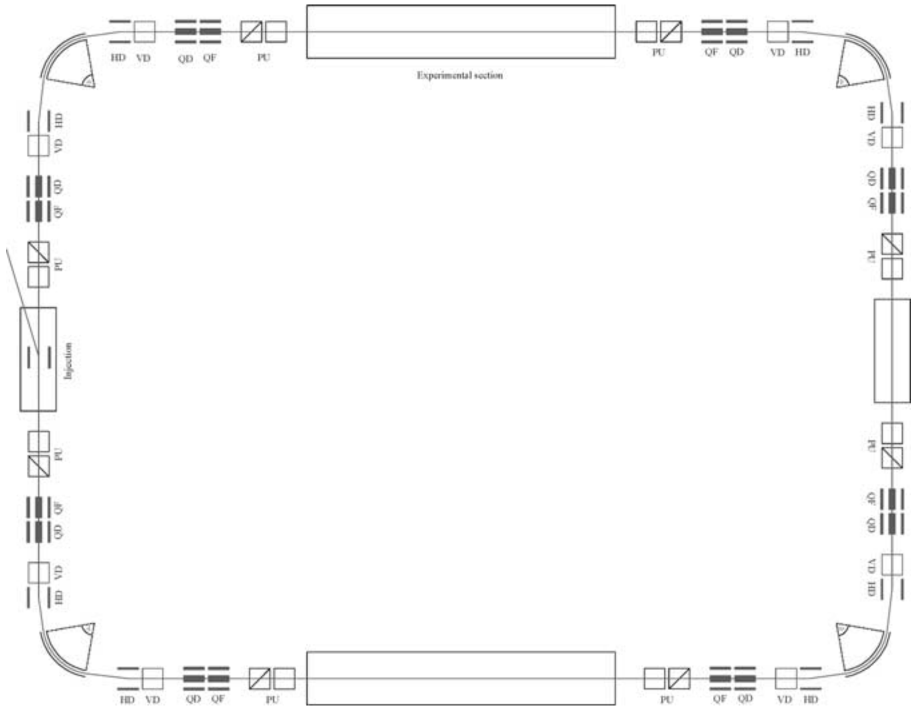

Figure 1. Layout of the complete ring.

1.2. BEAM PROPERTIES

The beam will leave an ECR ion source [3] with an energy of up to 50 keV, corresponding to a velocity of protons of $0.01c$. Thus relativistic effects can be neglected in all calculations.

The aperture defines the maximum size of the circulating beam and is at a minimum of 30 mm in the cylindrical deflectors.

One main difference to magnetic type rings is the mass-independence of the necessary fields. Theoretically, one can set up the fields for one charge/energy relation and switch from one ion type to another without changing any of the rings' parameters.

This advantage could already be verified at the two existing electrostatic rings at ISA [4] and at KEK [5].

2. Lattice

2.1. INJECTION

The beam will enter the ring at an angle of 10° and is bend towards the axis by an electric "fast kicker" inflector of two 100 mm × 70 mm copper plates placed at a distance of 50 mm.

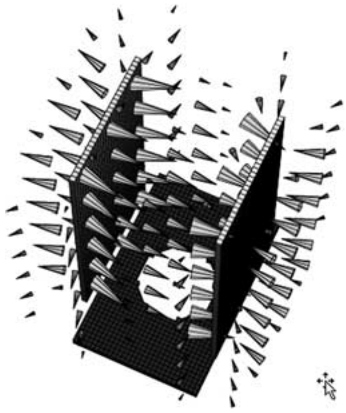

Figure 2. MAFIA plot of the calculated field in a 10° electrostatic deflector.

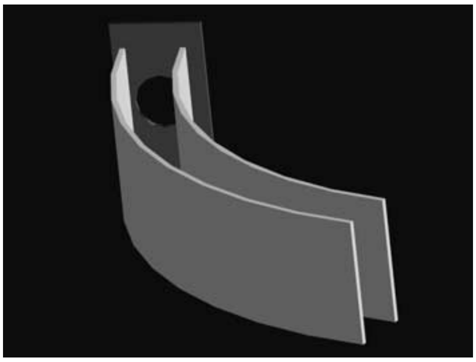

Figure 3. Rendered image of 70° cylindrical deflector with zero Volt shield in the background.

The field of 1.8 kV/cm is switched off after the beam has traveled half the circumference of the machine, i.e. 1.5 μsec (p).

2.2. BENDING SECTIONS

The bending is done in two steps: First, a 10° electro-static deflector bends the beam away from the straight section, afterwards a 70° cylindrical deflector and another 10° parallel plate deflector add up to a 90° bend.

This allows to detect neutral particles at the end of the straight sections. In addition, interaction processes with laser or electron beams can be studied.

The cylindrical deflector will be placed in a pillbox cavity, which guarantees good accessibility and space for diagnostic elements. Its two plates are 3 cm apart, requiring a field of 4 kV/cm to keep the beam on a mean radius of 25 cm.

Zero Volt shields at the entrance and exit of the deflector limit the maximum size of the beam to 30 mm and reduce fringe fields.

Figure 4. Quadrupole mounted on support.

It should be noted that, in contrast to magnetic bending sections, the longitudinal energy is not conserved in the electrostatic case. Particles entering the cylindrical deflector off-axis do see a longitudinal field component and therefore get accelerated or decelerated.

Finally, there is a stronger focusing in the horizontal plane as compared to magnetic bends, but no focusing in the vertical plane. Closed orbit correction is done by a small vertical deflector.

2.3. FOCUSING ELEMENTS

Transverse confinement of the circulating beam is done with pairs of quadrupole doublets. Electrodes of 10 cm length produce a field homogeneous enough to allow an aperture of about 5 cm.

A total number of at least 4 doublets will give the possibility to change the properties of the beam in a wide range. The required voltages are up to ± 1 kV, depending on the desired shape of the beam.

The ideal shape of hyperbolic electrode surfaces is approximated by cylindrical electrodes of radius $r = 1.1468 \cdot r_{\mathrm{aperture}}$, which is no problem at these low field levels.

3. Vacuum system

The lifetime of the circulating beam is mainly limited by collisions with the residual gas and therefore a vacuum pressure in the order of 10^{-12} mbar is envisaged. Therefore, all vacuum chambers will be built from stainless steel. Oxygen-free, gold-plated copper was chosen for the electrodes and aluminum-oxide for insulation purposes.

A combination of turbomolecular pumps and NEG foils placed directly inside the vacuum chambers will be used.

Table I. List of design parameters

General parameters	
Maximum energy	50 keV
Circumference	17.91 m
Revolution time	3.5 μs (p)
10° deflectors	
Plate area	100 mm × 70 mm
Plate distance	50 mm
Voltage	±4.5 kV
70° deflectors	
Height	70 mm
Radii	235 mm and 265 mm
Voltage	±6 kV
Quadrupoles	
Length	100 mm
Outer radius of electrodes	29 mm
Voltage	±1 kV

The whole system, including diagnostics and control system is bakeable to 250°C.

4. Diagnostics

Diagnostics will include beam-position monitors, Faraday cups, scrapers, scintillators with CCD cameras and single particle detectors. Since only about 10^5 ions will circulate the ring, a good signal/noise ratio of the amplifiers is needed [6].

The whole machine will be controlled by a LabView/Group3 system.

5. Present status and outlook

The present parameters of the planned storage ring are given in Table I.

The construction of a small pillbox cavity has just been completed. Its size has been chosen to be big enough to house all the different electrodes and diagnostic elements.

The layout of the optical elements is finished and the electrodes have been manufactured.

The effects of electrode displacements, surface errors and fringe fields will be studied as well as questions arising when dealing with XHV. Furthermore, the control system will be tested.

The next step will be the construction of one quarter of the ring.

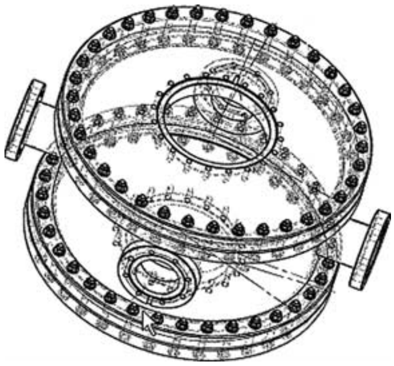

Figure 5. Drawing of pillbox-type test cavity.

Acknowledgements

The authors would like to thank Søren Pape Møller for his support throughout the design process. This work was supported by BMBF and Studienstiftung des deutschen Volkes.

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