RING OF FIRE

C. P. Welsch[1], J. Ullrich, MPI-K, Heidelberg
C. Gläßner, K.-U. Kühnel, A. Schempp, IAP, Goethe University, Frankfurt
H. Schmidt-Böcking, R. Dörner IKF, Goethe University, Frankfurt
Germany

Abstract

A small electrostatic storage ring is the central machine of the **F**rankfurt **I**on sto**R**age **E**xperiments which will be built up at the new Stern-Gerlach-Center of Frankfurt University. With ion energies up to 50 keV it enables the analysis of complex many-particle systems from atoms to very large bio molecules. The high luminosity of the beam allows measurements with many orders of magnitude better resolution compared to traditional measurements. It will be combined with existing experiments, like the reaction microscope COLTRIMS [1], [2] and the ECR ion source [3]. In comparison to earlier designs [4], the ring lattice was modified in many details: Problems in earlier designs were related with e.g. the detection of light particles and highly charged ions with different charge states. Therefore, the deflectors were redesigned completely, allowing a more flexible positioning of the diagnostic elements. In this contribution, the final design of the storage ring is presented and the layout of all elements given.

RING LATTICE

The machine consists of two different types of bending elements – parallel plate and cylindrical deflectors – and quadrupole doublets for transverse focusing of the beam. The symmetry of the storage ring was chosen to be as high as possible. As can be seen in Fig.1, experimental requirements had a great influence on the design of the vacuum chambers. Easy access to all the elements is important for a machine, where a wide range of fields will be covered and the included diagnostic elements will have to be changed depending on the experiment carried out.

Therefore, pillbox-type cavities were used allowing easy adjustment of the optical elements and giving enough room for additional detectors.

The size of machine of about 7m x 7m is dominated by the experimental sections, where a length of 2m is foreseen for in-ring experiments like a reaction microscope or an electron target. By splitting up the 90° bend in the corner sections into two 15° parallel plate deflectors and one 60° cylinder deflector, single turn injection can be done along one of the straight sections with one of the deflectors being switched off in the beginning.

After energy separation in the injection channel, the beam is directly injected into the machine. Once half of the ring’s circumference is filled with ions, the parallel plate deflector is turned on and the beam can be stored. The revolution time of the lightest ions that will be stored, protons, is roughly 10 μs.

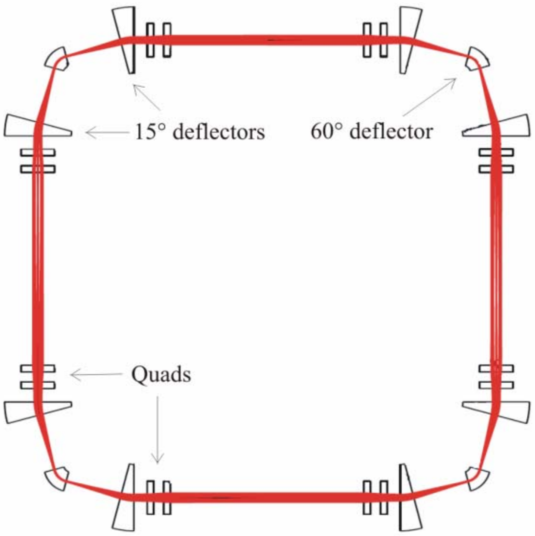

Figure 1: Beam envelope calculated with COSY infinity. Transverse dimensions are multiplied by factor 5.

In addition, the separation of the bending elements in the corner sections allows easy monitoring of neutral particles created along the straight sections and also the injection of merged beams.

A bunched beam structure is realized by an Rf driven drift tube where voltages < 100 V can be applied to counteract longitudinal debunching effects.

Different stable working points exist and the machine can be adjusted to the experimental needs. The calculated envelope function for one such solution is shown in Fig. 1. It can clearly be seen, that the horizontal size is smallest in the 60° bending section, where also the mechanical aperture is at its minimum. In the experimental sections, a larger beam size is more easily manageable.

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[1] carsten.welsch@mpi-hd.mpg.de

OPTICAL ELEMENTS

As pointed out before, the ring consists of separated function bending and focusing elements. The lattice was kept as simple as possible in order to guarantee easy operation. In comparison to earlier designs [4], a number of parameters had to be changed taking into account the requirements of envisaged experiments.

15° Parallel Plate Deflector

Injection as well as part of the 90° bending in the corner section will be realized with a parallel plate deflector as shown in Fig. 2.

Figure 2: 15° electrostatic parallel plate deflector with central mesh for the detection of light charged fragments.

The ions follow a parabolar trace inside this element with the design particle entering in the middle of the deflector. Voltages of +/- 6.7 kV have to be applied on the electrodes, which are separated by a distance of 10 cm. In order to reduce the disturbing effects of fringe fields [5] to a minimum, the electrodes were designed with a length and height of 200 mm. This leads to a field inhomogeneity in the central region of the element of less than $1 \cdot 10^{-4}$.

The support of the electrodes at the same time acts as a grounded shield and reduces the fringe fields in the entrance and exit region considerably.

60° Cylinder Deflector

The main bending in the storage ring is done in 60° cylinder deflectors placed in pillbox-type cavities. In contrast to the parallel plate deflectors, these elements are limited to a specific bending angle by their geometrical dimensions. Again, grounded shields at the entrance and exist of this element limit the fringe field effects on the circulating beam.

Experimental requirements had a large impact on the final layout of the element. If one assumes that the longitudinal velocities of all particles involved in fragmentation experiments stays constant and the complete energy release is transferred into transverse motion of the fragments, one can calculate a cone in which all fragments propagate through the machine. It comes out that heavy fragments at 50 keV beam energy with a $|\Delta m|/m < 20\%$ compared to the original beam are displaced by only a few mm and still enter the cylinder deflector.

In simulations with SimIon it was found that, depending on the ion species and the corresponding charged fragments, the latter will eventually hit the deflector electrodes under a small angle and get lost. In order to be able to detect these fragments, a central gap was introduced into both electrodes and additional correction electrodes were placed to compensate the field disturbances.

Figure 3: Electrostatic cylinder deflector with central gap for detection of charged fragments with small mass differences as compared to the original beam

While the field in the central region of the element is identical to the field inside a conventional deflector with solid plates, the charged fragments can leave the element and be detected in the outside region.

Quadrupole Doublets

The transverse dimensions of the circulating beam are controlled by electrostatic quadrupole doublets. During operation, it is important, that all of the fields in the machine can be adjusted independently and thus a clear separation of the fields is required [6].

In existing electrostatic storage rings, closed orbit correction is done with additional steerers placed close to the corner sections of the machine. If one aims for detecting all the particles created in a fragmentation process, these elements avoid placing the detectors in the region. For that reason and for a clear decoupling of the quadrupole lenses, a vertical steerer was introduced as shown in Fig. 4.

Figure 4: Electrostatic quadrupole doublet with integrated steerer

The distance between the two quadrupoles was extended to 150 mm, which completely decouples the fields of the elements. In case the beam is disturbed by e.g. field errors, small voltages can be applied on the vertical steerer to counteract beam shifts. The horizontal steering is achieved by parallel plate deflectors, where small voltages can be added, if necessary.

The electric and mechanic parameters of the machine and its components are summarized in table 1 [7].

Table 1: Summary of design parameters

General Parameters	
Maximum energy	50 keV
Circumference	25.45 m
Revolution time	9.9 µs (p)
15° deflectors	
Plate area	200 mm x 200 mm
Plate distance	100 mm
Mesh height	80 mm
Voltage	+/- 6.7 kV
60° deflectors	
Height	100 mm
Radii	235 mm and 265 mm
Shield distance	10 mm
Voltage	+/- 6 kV
Quadrupoles	
Length	100 mm
Distance between lenses	90 mm
Aperture radius	25 mm
Shield distance	10 mm
Voltage	+/- 3 kV
Steerer length	50 mm
Steerer plate distance	60 mm

CONCLUSION

The electrostatic storage ring of the Frankfurt ion storage experiments will allow covering a wide range of possible fields and serve as a true multi-purpose, multi-user facility. Due to the mass-independence the electrostatic rigidity, all ions from light protons to heavy bio molecules can be stored in the machine.

In comparison to earlier design studies, major changes in the layout of the optical elements were made, taking into account the requirements of envisaged experiments. As the central machine of the new Stern-Gerlach Center at Frankfurt University, the electrostatic storage ring will combine the efforts of the institutes of nuclear and applied physics, biophysics and physical chemistry and allow novel views into the dynamics of complex organic matter.

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