AN ELECTROSTATIC STORAGE RING FOR MOLECULAR SCIENCE

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Abstract

An electrostatic storage ring with a circumference of 8 m was designed for studying molecular science. A race-track ring consists of two 160° deflectors, four 10° deflectors and four quadrupole doublets. For the main deflectors, we have adopted a cylindrical shape, which is one of the main differences from the lattice at ELISA [1], where spherical deflectors are used. As a result, there is no vertical node at the center of the deflectors, which may eliminate one of the origins of the intensity-related beam losses observed at ELISA. Ion beams with an energy of 20 keV from an ECR ion source are injected into the ring after being momentum-analyzed. The entire system has been completed and installed. The design and performance of the electrostatic storage ring are presented.

1 INTRODUCTION

Since the late 1980s, many storage rings with electron coolers have been operational, and some of them have been used for the research of atomic physics. For atomic physics using these cooler rings, some new phenomena were found, especially concerning the electron-ion recombination of molecular ions. The object of the present research is directed to heavier molecular ions. One of the difficulties in studying heavy molecular ions with magnetic storage rings is the increasing magnetic rigidity with ion mass. An electrostatic storage ring is more suitable for such ions because the electric rigidity is independent of the ion mass. There are also many advantages of using electrostatic storage rings, such as small ring size and ease of beam injection. The ring is expected to be very useful for the research of molecular science in the future. Pioneering work concerning the electrostatic storage ring was performed by S.P.Moeller [1], and many heavy ions have been stored in the ring ELISA. However, at ELISA it was observed that the beam lifetime decreases with increasing beam intensity. This was suspected to result from the nodes of the beam envelope in the middle of the deflectors where intrabeam stripping occurs due to the high ion densities. In this paper, we report on the design and performance of a ring without a node.

2 LATTICE DESIGN

The difference in the equation of motion between magnetic and electric storage rings is in the bending element, as given by the following equations:

Magnetic bend:

(Horizontal) $$\frac{d^2x}{ds^2} + \frac{1-n}{\rho^2}x = \frac{1}{\rho}\frac{\Delta p}{p},$$

(Vertical) $$\frac{d^2y}{ds^2} + \frac{n}{\rho^2}y = 0.$$

Electric bend:

(Horizontal) $$\frac{d^2x}{ds^2} + \frac{3-n}{\rho^2}x = \frac{1}{\rho}\frac{\Delta W}{W},$$

(Vertical) $$\frac{d^2y}{ds^2} + \frac{n-1}{\rho^2}y = 0,$$

where n is the field index and momentum p is related to the kinetic energy (W) by $\Delta W / W = 2\Delta p / p$ non-relativistically. The values of n for an electric bend are 1 and 2 for cylindrical and spherical deflectors, respectively. As can be seen in the above equations, the horizontal focusing force is stronger in an electrostatic deflector than in a magnetic bend, while for the vertical focusing force the situation is reverse. This requires a different lattice design for the electrostatic ring from that for the magnetic ring. We compared two race-track lattice with different bending elements. The halves of these rings are composed of following elements:

a) Q_f+Q_d+10°D+80°D(Cy)+Q_d+80°D(Cy)+10°D+Q_d+Q_f
b) Q_f+Q_d+10°D+160°D(Cy)+10°D+Q_d+Q_f,

where Q_f(Q_d) is a horizontally focusing (defocusing) quadrupole and D(Cy) is cylindrical deflector. We calculated the optical amplitudes for a ring with a circumference of about 8 m. Figure 1 represents beta functions and beam envelopes for a beam with a momentum width of 10^{-3} and an emittance of 15π mm·mr.

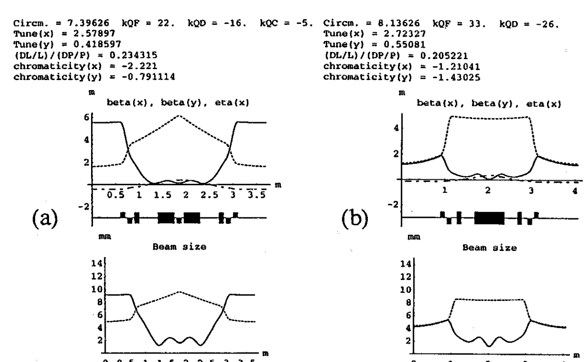

Figure 1: Lattice functions and beam envelopes for (a) Q_f+Q_d+10°D+80°D(Cy)+Q_d+80°D(Cy)+10°D+Q_d+Q_f, and b) Q_f+Q_d+10°D+160°D(Cy)+10°D+Q_d+Q_f.

As can be seen in the figure, both lattices have no node in the vertical direction. We chose lattice b) because its beam envelope is smoother than that for a) and the number of elements is less for that of lattice b).

3 INJECTOR AND STORAGE RING

3.1 Ion source and momentum analyzer

Atomic and molecular ions are produced in a compact ECR ion source [2] with an acceleration voltage of 20 kV, and are injected into a beam-analyzing magnet. The beams are then momentum-analyzed by a double-focusing 90° bending magnet with a radius of 1.2 m and a maximum magnetic rigidity of 1.8 Tm. The typical momentum resolution is $\Delta p/p \sim 10^{-3}$. The momentum-analyzed beam is then injected into the ring through a matching section consisting of an electrostatic quadrupole triplet.

The vacuum pressure in the ion source is 10^{-5} mb, while the vacuum in the ring is 8×10^{-11} mb without beam loading. The high vacuum was attained by a differential pumping system consisting of a cryo-pump, 4 turbo molecular pumps, an ion pump and 3 Ti sublimation pumps installed in the beam-transport line.

3.2 Storage ring

The layout of the ring is shown in Fig. 2 and the deign parameters are given in table 1.

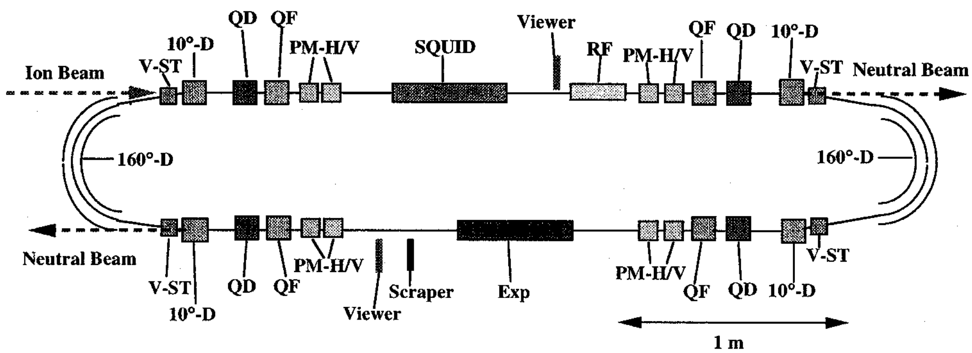

Figure 2: Layout of the electrostatic storage ring.

Table 1: Design parameters for the electrostatic ring

Maximum energy	30 keV
Circumference	8.136 m
Revolution time	22 µs (N_2^+)
Betatron tunes Q_H,Q_V	2.72, 0.55
Chromaticities ξ_H, ξ_V	-1.21, -1.43
Momentum compaction	0.205
160°cylindrical deflectors	
central radius	250 mm
gap	30 mm
nominal voltage	± 3.6 kV
10° parallel plate deflectors	
gap	50 mm
length	100 mm
nominal voltage	± 2.6 kV
Quadrupoles	
inscribed radius	25 mm
length	100 mm
nominal voltage	± 0.75 kV
RF	
drift tube length	203 mm
frequencies	10-200×h kHz
voltage	<10 V

Deflectors and quadrupoles

In order to avoid charge from being deposited on the oxide layers on the surface of the electrode, the inside walls of the deflectors and quadrupoles are gold-plated. The field clamps at the entrance and exit of the electrodes define the effective field length of the elements. Quadrupole fields are approximately formed by cylindrical electrodes.

Injection

A beam chopped by a vertical steering electrode in the transport line is injected into the ring. During injection, the high voltage for the first 10° deflector is turned off, and after filling the beam in the ring it is turned on.

Beam monitor

The injected beam profile is observed destructively with two viewers made of Al_2O_3 plates. The surface of the plates is covered by a tungsten mesh. Thus, the beam current hitting the plate is also measured. Four horizontal and vertical position monitors give position information nondestructively. The circulating beam current is measured nondestructively by a SQUID-current measuring device [3] with a sensitivity of 1 nA, which is planned to be installed in the ring.

Scraper

Two beam scrapers define the maximum beam size both horizontally and vertically.

Vacuum

A vacuum pumping system comprises 4 ion pumps and 6 Ti sublimation pumps. The beam pipes are degassed before installation by heating them at a temperature of

950°C in a vacuum. The entire ring is bakeable at a temperature of less than 300 °C with sheath heaters controlled by thermostats.

RF

The beam is bunched with an RF electrode consisting of a 20-cm drift tube, which is driven by a frequency synthesizer.

Neutral beam monitor

A neutral beam produced in collisions with the rest gas is measured by a micro-channel plate installed in the vacuum extension downstream of the 10° deflector. The count rate of the neutral beam is proportional to the number of stored ions, which gives exact information about the beam lifetime.

4 BEAM TEST

A beam from the ECR ion source was momentum-analyzed and injected into the ring after being chopped. The beam was bunched by the RF and its intensity was monitored by electrostatic position monitors. A beam test was performed on N^+, O^+, N_2^+, O_2^+, NO^+ and H_2O^+ ions at an energy of 20 keV. The voltages of the deflectors and quadrupoles agreed well with the design values within an error of 10%. The coasting NO^+ beam lifetime measured by the neutral beam monitor is shown in Fig. 3.

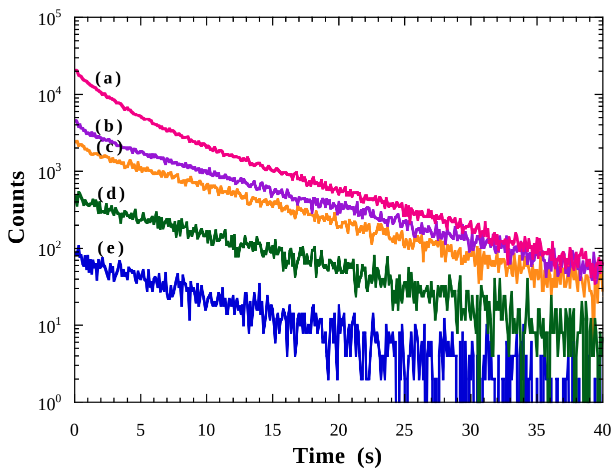

Figure 3: Time dependence of the neutral-beam production rate for NO^+ ions at currents of (a) 600 nA, (b) 130 nA, (c) 70 nA, (d) 15 nA and (e) 4 nA.

The 1/e-lifetime at low current is about 10 s at a vacuum pressure of 1×10^{-10} mb, while it decreases at a higher current. The lifetime does not depend much on the intensity at a current of less than about 100 nA, which is tolerable for practical use, like atomic-collision experiments. The lifetime at low intensities is mostly dominated by the vacuum pressure; a further extension of the lifetime is expected after a sufficient bakeout of the vacuum pipes.

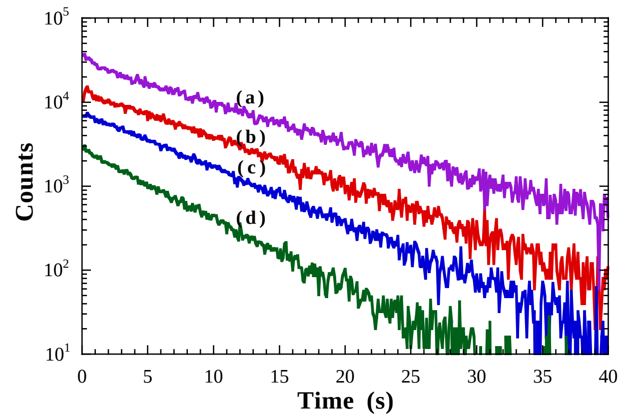

Figure 4: Time dependence of the neutral-beam production rate for (a) NO^+ ($\tau_{1/e}$~9.4 s), (b) H_2O^+ (8.1 s), (c) O_2^+ (6.7 s) and (d) N_2^+ (5.2 s).

The lifetime also depends on the ion species, as can be seen in Fig. 4, which reflects the physical characteristics of each molecular ion.

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