Proceedings of the 1999 Particle Accelerator Conference, New York, 1999

OPERATIONAL EXPERIENCE WITH THE ELECTROSTATIC STORAGE RING, ELISA

S. Pape Møller[*] and U.V. Pedersen, ISA, Univ. Aarhus, DK-8000 Aarhus C, Denmark

Abstract

The design and initial operation of the first ion storage ring using electrostatic deflection and focusing elements was described in [1,2]. In the present contribution, the design will be only briefly described, and emphasis will be given to the operational experience with the storage ring. At the time of writing this contribution, different beams of both positive and negative atomic and molecular ions of masses ranging from 4 to 840 AMU's have been stored. The residual-gas pressure, which in the best cases has been below 10^{-11} mBar, determines the lifetimes of low-intensity beams of stable ions. Lifetimes up to more than 30 seconds have been observed. Intensity-related losses of beam are observed when the number of injected particles is higher than a few times 10^5. These losses are not understood at present. Future research programs will be outlined, including storage of very heavy bio-molecules.

1 INTRODUCTION

Research in low- and medium-energy atomic and nuclear physics has progressed tremendously with the introduction of small storage rings into these areas [3]. These storage rings for both light and heavy ions have evolved from the high-energy storage rings and use magnetic elements for deflection and focusing. The rings have circumferences larger than 40 m and rigidities larger than 2 Tm. In [1] it was proposed to construct a small storage ring using electrostatic devices for deflection and focusing. The design and first results from the commissioning of this electrostatic storage ring, ELISA, were described in [2].

The alternative storage device used to confine charged particles for extended periods of time in a small volume of space is the electromagnetic trap [4], in which the confinement is provided by static (Penning trap) or varying (Paul trap) electromagnetic fields. In an ion trap, the ions have a vanishing average velocity as opposed to the energetic ions in a straight section of a storage ring. We also mention the recent development of a storage device consisting of two 180° electrostatic mirrors [5].

The layout of the ring is given in Fig. 1. The lattice consists of two 160° spherical electrostatic deflectors (SDEH), each having a 10° parallel-plate electrostatic deflector (DEH) and an electrostatic quadrupole doublet (QEH/V) on each side. The resulting lattice functions are shown in Fig. 2 and a very strong waist in the middle of the spherical bends, characteristic of this lattice, is seen. One of the main differences between electrostatic and

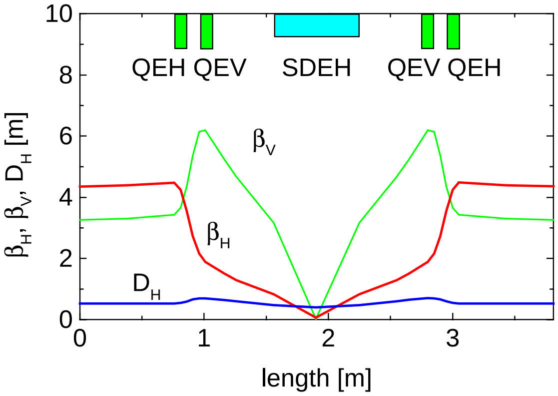

Figure 2: Lattice functions for ELISA.

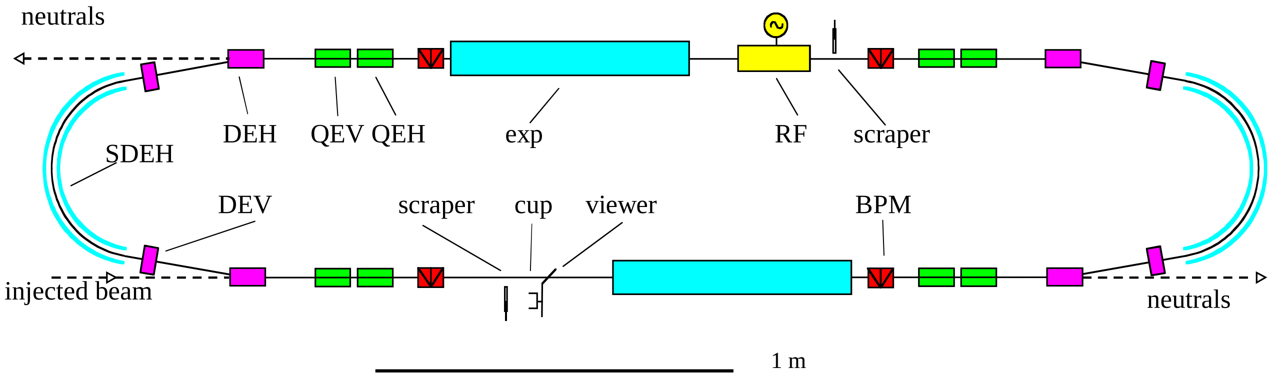

Figure 1: Layout of the ELISA storage ring. The abbreviations are explained in the text.

---

[*] FYSSP@IFA.AU.DK

0-7803-5573-3/99/$10.00@1999 IEEE.

magnetic deflection is that the longitudinal energy is not conserved in the electrostatic case. This effect is actually what gives rise to the strong horizontal focusing in the 160° bends. Furthermore, such spherical deflection electrodes give rise to equally strong horizontal and vertical focusing. Closed-orbit correction can be performed with the four vertical correctors (DEV) and the four 10° bends.

Diagnostics of the injected beam can be made using the Faraday cup and the fluorescent-screen viewer, and the stored beam can be monitored with the four horizontal and four vertical beam-position monitor pick-ups. In addition, the two sets of scrapers can be used for beam size and position measurements. Finally, there are two ports for detection of ions having had a charge-changing collision in the straight sections. These neutralised ions are observed with a channel-plate detector with a fluorescent screen and provide a direct real-time observation of the projection of the circulating beam.

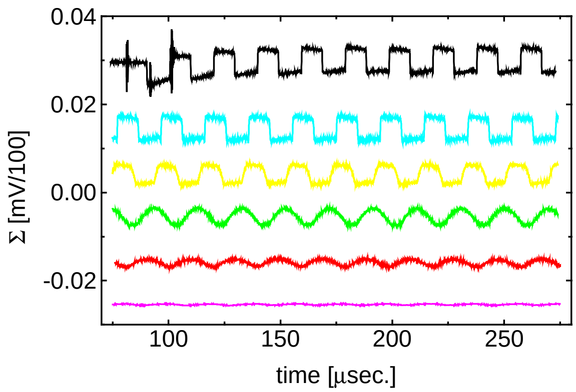

Figure 3: BPM sum signals from a chopped 22 keV N_2^+ beam. For details, see the text.

The high-voltage supplies are designed to allow storage of ions with kinetic energies less than 25 keV, and we stress here that this can be ions of almost any mass.

2 COMMISSIONING RESULTS

During the one year that has passed since the commissioning of ELISA started, a wealth of different ions have been stored, and the advantage of an electrostatic ring to store ions of different masses for the same setting of the lattice elements has been verified. There are, however, small adjustments to be made between positive and negative ions, and between light and heavy ions. This is presumably caused by stray magnetic fields from the ion pumps and the magnetic field of the earth. The species used so far include N^+, Ar^+, Xe^+, D_2^+, N_2^+, CO^+, O^-, O_3^-, $C_{36\text{-}96}^-$, Al_x^-, Cu_x^-, Ag_x^-, $C_2H_2^-$.

The first observations are made with the beam-position monitors, which provides both a Σ and a Δ signal reflecting the circulating intensity and the position of the beam, respectively. The Σ signals from a chopped 22 keV N_2^+ beam consisting of around $5\cdot10^6$ ions are shown in Fig. 3 at injection time and 1, 5, 15, 30 and 60 msec. later. Successive revolutions are clearly seen, and the signals show that there are no beam losses during the first many milliseconds. The de-bunching of the beam owing to the momentum spread is observed at late times.

When the beam has de-bunched, the intensity can not be measured with the pick-up's. The circulating intensity can, however, be monitored with the detectors at the end of the straight sections, since the number of neutralised ions is proportional to the circulating intensity and the residual-gas pressure. In fig. 4 is shown this neutral particle yield for four different injected currents of 1.5, 10, 44 and 140 nA of 22 keV O^-. These currents correspond to $1.4\cdot10^5$, $1\cdot10^6$, $4.4\cdot10^6$ and $1.4\cdot10^7$ ions, respectively. The remaining beam is kicked out after 55 seconds, and the signal seen after this time corresponds to the background in the detector. An exponential decay is observed for low currents, with a lifetime of 20 seconds. This lifetime is compatible with the electron detachment cross section for residual-gas collisions at a pressure of a few times 10^{-11} mBar. Although the pressure is not known very accurately, increasing the pressure in ELISA has proven a lifetime dominated by the residual gas.

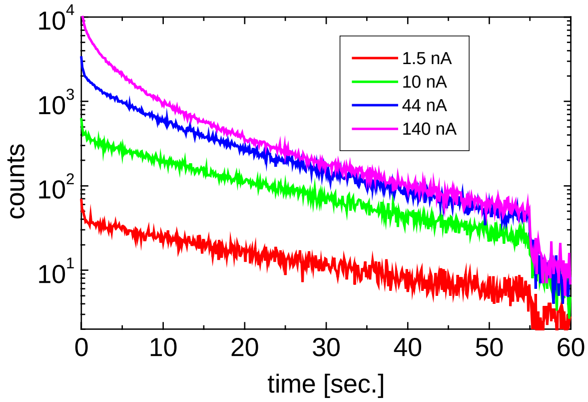

Figure 4: Neutral particle yield as function of time for four different injected currents of O^-.

Cross sections for residual-gas interactions (electron capture and loss) are almost energy-independent at these low energies, which in turn means that storage times will scale inversely proportional to the velocity. We have measured the lifetimes of a O^- beam at 22 and 11 keV to 26 and 33 seconds, respectively, in accordance with this scaling. The longest lifetimes observed are a lifetime of 36 seconds for a 22 keV Xe^+ beam.

A comparison of residual-gas dominated lifetimes of a positive and negative oxygen beam at 22 keV is made in Fig. 5. The lifetime of the positive beam is around 11 seconds, whereas the lifetime of the negative beam is around 26 seconds. This difference is explained by the electron-capture cross section of O^+, which is approximately a factor of 3 larger than the electron-detachment cross section of O$^-$ at low energies. Both measurements are made with injected currents of around 1 nA and similar residual-gas pressures.

Since the residual-gas pressure determines the lifetimes of low-intensity beams, longer lifetimes can be obtained by reduction of this pressure. One possibility with a small ring like ELISA is the possibility to cool the whole ring, which in turn reduces the out-gassing of the vacuum chamber walls. This has been tried with a reduction of the pressure to a few times 10^{-12} mBar. ELISA was cooled with liquid nitrogen, using the same insulation box as used during bake-out.

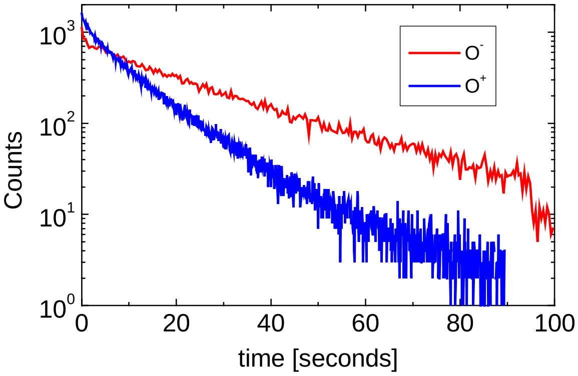

Figure 5: Comparison of lifetimes of O$^+$ and O$^-$ beams at 22 keV.

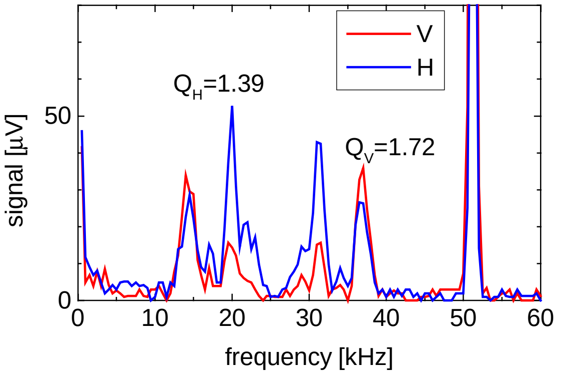

Figure 6: Betatron frequencies for a 22 keV CO$^+$ beam in ELISA.

For larger currents, a reduction in the lifetime is seen in Fig. 4 at early times, corresponding to an intensity dependent lifetime. The origin of this effect is as yet unknown. Estimates of intra-beam scattering times give characteristic times of the order of hours, much longer than the characteristic times observed. Tune shifts are also too small (of the order of 0.001) to have a significant influence. Also intra-beam stripping, i.e. loss of ions due to electron detachment in O$^-$-O$^-$ collisions, can not explain the observations. Similar effects observed for positive beams corroborate this last statement. Measurements of beam profiles do not indicate a large emittance increase for the intense beams.

Looking at the lattice functions in Fig. 2 makes one focus on the very low beta-functions in the middle of the spherical deflectors, nominally equal to 0.1 and 0.02 m horizontally and vertically, respectively. It has been proposed [6] that the losses might be due to excitation of resonances by the strong envelope modulation. Although such an effect evidently exists, quantitative estimates of the influence are not yet available. A remedy for such an effect would be a modification of the lattice in order to make the lattice functions smoother. Such a modification is, however, not easy with a race-track configuration due to the strong focusing from electrostatic bends. One suggestion would be to replace the 160° spherical bend by two 80° cylindrical bends and a vertically focusing quadrupole, as suggested in [7].

Experience has shown that ELISA is rather sensitive to the betatron tunes. Measured tunes of a CO$^+$ beam are shown in Fig. 6. The tunes are measured by a FFT analysis of the Δ signal from a pick-up for a mis-steered chopped beam. The non-integer parts of the betatron frequencies are directly observed together with the revolution frequency at 52 kHz. In an electrostatic ring as ELISA, where the deflectors also are focusing, there is a strong coupling between the position and the tunes. This is a complication and a restriction in tuning the machine.

3 CONCLUSIONS AND OUTLOOK

The principle of an electrostatic storage ring has been proven to work and the first experiments studying the decay-properties of beams directly or by means of lasers are in progress. For these experiments, the intensity limitations observed are unimportant, as it also is for the planned study of stored bio-molecules. However, there are planned experiments aiming to study the interaction between stored ions and electrons, where higher intensities are required, and a solution to the intensity-problem will be sought.

4 REFERENCES

[1] S.P. Møller, Proc. 6'th European Particle Accelerator Conference, Stockholm 1998, p. 73.
[2] S.P. Møller, Nucl. Instrum. Methods in Physics Research A **394** (1997) 281
[3] S.P. Møller, Proc. 4'th European Particle Accelerator Conference, London 1994, p. 173
[4] R.C. Thomson, Advances in atomic, molecular and optical physics **31** (1993) 63
[5] M. Dahan et al, Rev. Sci. Instrum. **69** (1998) 76
[6] Y. Senichev, private communication
[7] T. Tanabe and I. Watanabe, private communication