INTENSITY LIMITATIONS OF THE ELECTROSTATIC STORAGE RING ELISA

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Abstract

Intensity limitations of ELISA, the low-energy electrostatic storage ring, were previously reported [1]. Theoretical considerations and simulations suggest that the beam losses may be due to non-linear effects [2]. These non-linearities arise mainly from the spherical deflectors used in ELISA. The fields from cylindrical deflection plates are much more linear. Hence ELISA has been modified to use cylindrical deflectors, and the results after this change are shown. Furthermore, laser diagnostics[3] have been used to characterise the circulating beam, which in this case is positive magnesium ions.

1 INTRODUCTION AND HISTORY

Storage rings have proven to be a valuable tool in atomic physics. These storage rings are operating with low-energy ion beams and are relatively small, and hence not very expensive. However, they represent a major investment for most physics institutes carrying out atomic physics research. This was one of the motivations to develop storage rings based on electrostatic deflection and focusing elements. In addition, there are inherent advantages in such storage devices as compared to magnetic storage rings.

Electrostatic storage rings are to some extent complementary to ion traps, where ions are stored at very low energy and without any preferred direction of motion.

The electrostatic storage ring ELISA has now been in operation for almost two years, and several experiments that prove the above-mentioned advantages, have been performed. Early on, a limitation in the stored currents was observed, and the following should be considered as a contribution to the understanding and the improvement of these limitations.

2 DESCRIPTION AND CHANGES OF THE DESIGN OF ELISA

2.1 General Layout

The structure of the electrostatic storage ring ELISA can been seen on fig.1. The lattice consists of two 160E and four 10E horizontal deflectors (DEH), four quadrupole doublets (QUAD) and four vertical steerers (DEV). Detectors at the end of the straight sections are providing information for the experiments, but are also important for operation of the ring. The maximum ion energy, as determined by the supplies, is 25 keV and the ring can be operated with horizontal and vertical tunes between 1 and 2.

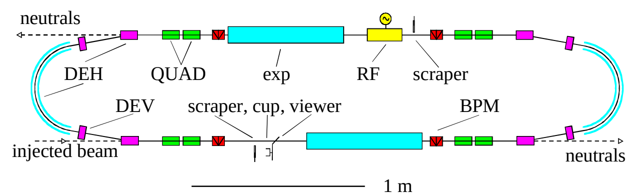

Figure 1: Layout of ELISA.

2.2 Changes to the main deflectors

The intensity-dependent losses are thought to originate from non-linearities of the lattice in combination with

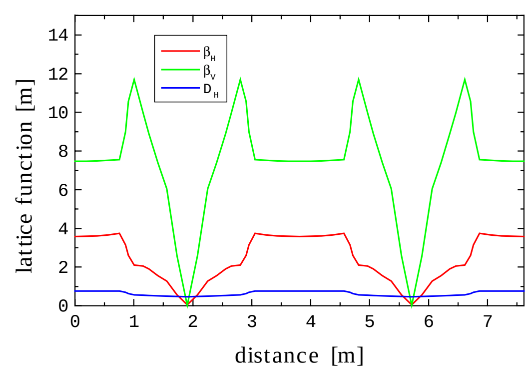

Figure 2: Lattice functions with spherical deflectors.

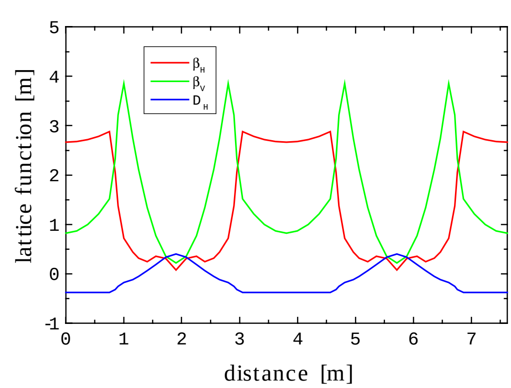

Figure 3: Lattice functions with cylindrical deflectors.

the inherent coupling between the longitudinal and the transverse planes in the deflectors [2]. Hence it was decided to change the 160Edeflectors from spherical to cylindrical deflectors. In this way the non-linearities should be reduced, as the cylindrical geometry only gives rise to non-linearities from the centrifugal term [2]. Furthermore this lattice has the possibility of operation without a strong waist in the deflectors, although giving rise to a vertical tune below one! The lattice functions for the two lattices are shown in figs. 2 and 3. The top part for the spherical deflectors with tunes of 1.37 and 1.12, and the lower for cylindrical deflection plates with tunes of 1.37 and 2.45 for the horizontal and vertical planes, resp.

At present it has not been possible to store a beam for more than around ten turns for the weak focusing lattice with a vertical tune of less than one. The reason for this is at present unknown.

3 OBSERVED INTENSITY LIMITATIONS

Already during the initial operation of ELISA, it was observed that there were excessive beam losses for high circulating currents [1]. Furthermore, these effects were observed for much smaller currents than expected, namely corresponding to tune shifts of the order of 0.001.

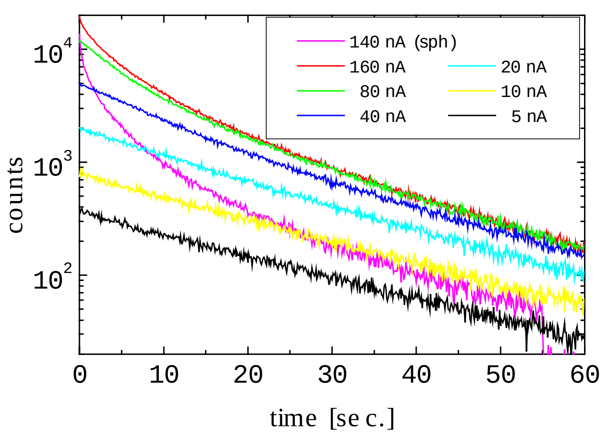

Figure 4: Decays of stored O^- beams at 22 keV.

Intensity limitations have again been investigated for ELISA with the new optics using cylindrical deflection plates. In fig. 4 is shown the circulating current of 22 keV O^- ions in ELISA as a function of time. The circulating current is deduced from the number of oxygen atoms detected at the end of a straight section with a channel-plate detector. At low currents (below a few 10's of nA), we observe an exponential decay with a lifetime of around 20 seconds stemming from residual gas interactions; electron detachment. Furthermore, the number of neutrals increase proportionally with the injected current. For higher currents, a faster decay is initially observed. It has also been verified using the neutrals detector, that the beam losses are not accompanied by an increase in the beam size. We note that the highest current of 160 nA corresponds to $1.8 \cdot 10^7$ ions. In the figure a curve is also shown from ELISA with spherical deflection plates (sph). It is seen that the situation is drastically improved with the cylindrical plates.

The tune acceptance has also been investigated and tune variations within ±0.015 are possible with only minor losses (<10%). Similarly the energy acceptance has been measured to ±0.5%; again corresponding to <10% losses.

4 BEAM OBSERVATIONS USING LASER DIAGNOSTICS

Diagnostics devices are very important for the operation of storage rings, and in particular in the search for anomalies. Laser diagnostics have proven to be able to perform transverse and longitudinal observations of low-energy ion beams with a high resolution and short measuring times [3]. The available lasers limit such observations to very few ion species, since the laser wavelength has to match a closed transition in the electronic structure of the ion. The favourite ion in Aarhus has been Mg^+, where, although the transition is at 280 Å, laser and photon detectors have successfully been developed. The techniques are based on overlapping a laser beam with the circulating ion beam. Longitudinal profiles, velocity profiles, can then be obtained by scanning the laser frequency or the beam energy across the resonance. Transverse profiles are obtained by imaging the flourescent light emitted on resonance onto a CCD camera.

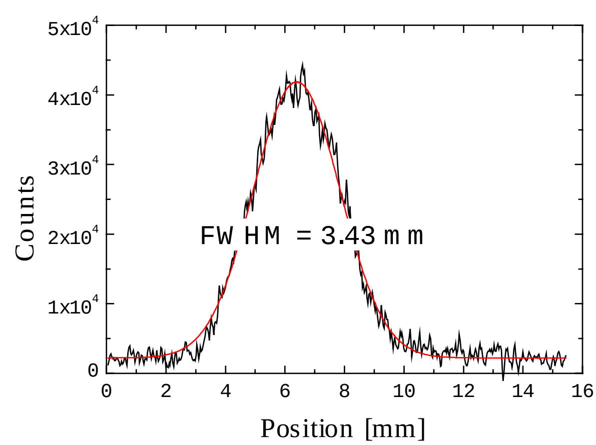

Figure 5: Vertical beam profile.

The laser measurements are made with a beam energy of 18.4 keV and the early version of ELISA with spherical deflectors. An example of a vertical profile is shown in fig. 5. This measurement was made with tunes of Q_H=1.37 and Q_V=1.12. The shown profile is made at 0.2 seconds after injection of 200 nA corresponding to $2.7 \cdot 10^7$ Mg^+

ions. A width of FWHM=3.43 mm is measured. This corresponds to the very small emittance of 0.3 π mm mrad (rms) for the nominal lattice (β_V=7.5m). Curiously enough, a similar width is observed in the horizontal plane, corresponding to twice as large an emittance.

More importantly, the width of the beam has been measured as function of time, and no increase (<10%) in the width is seen over the first 0.8 seconds of storage. Hence no emittance growth is observed. The first data-point corresponds, however, to an average over the first 0.1 seconds. Observations to later times than 1 sec. are uncertain, since the number of ions at resonance decrease with time as explained below.

A much better temporal resolution has been obtained for the longitudinal measurements. An example of such a measurement is shown in fig. 6, where the number of flourescense photons are shown as function of laser detuning, which has been converted into momentum via the Doppler shift. This spectrum is obtained 0.2 msecs. after injection. The width of the peak corresponds to $\Delta p/p=9\cdot 10^{-5}$ (rms). The small shoulder in the spectrum originates from reflected laser light in resonance with another fine-structure transition. The momentum spread has been measured as function of time, and the result is shown in fig. 7. The measurements have been made both by scanning the laser, but also by scanning the beam energy with a so-called post-acceleration tube. The measurements using the two different methods agree at early times, that is during the first 100 msecs. At later times, the measurements are uncertain, since the laser over time may modify the velocity profile. This is the effect used in laser cooling.

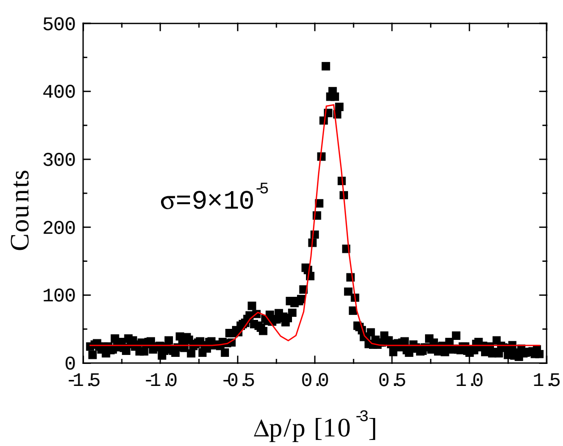

Figure 6: Longitudinal profile of ELISA beam.

It is seen that the velocity spread (rms) increase from around 10^{-4} at injection up to $7\cdot 10^{-4}$ in about 150 msecs. This increase is much faster than predicted from ordinary intra-beam scattering calculations; here the longitudinal e-folding times are of the order of seconds. Such intra-beam scattering calculations have been developed for magnetic storage rings, and do not take electrostatic potentials into account. Hence we interpret the abnormally fast increase in the velocity-spread as originating from scattering events, both binary collisions and space-charge like, in the electrostatic deflectors.

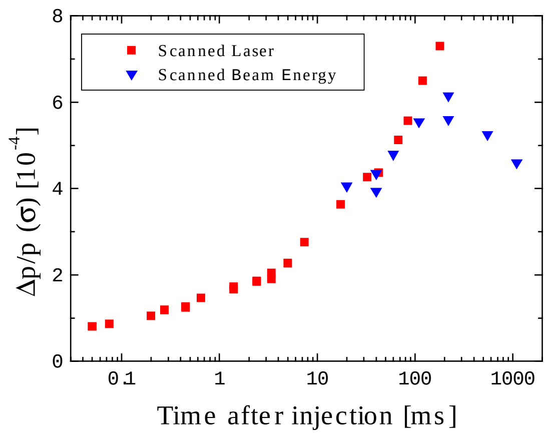

Figure 7: Momentum spread of beam as function of time.

5 SUMMARY AND FUTURE IMPROVEMENTS

A consistent explanation of the observations is that for large currents the velocity spread increases due to exchange of transverse and longitudinal energy in the deflectors [2]. The increased momentum spread will also lead to an increased tune spread via the chromaticity, but the increased tunespread seems to be within the allowed tune region, and the particles should not be lost on resonances. The number of particles in the tails of the distributions is, however, unknown.

We note also, that the lattice is non-linear, which leads to excitation of resonances. Another issue is that the circulating ions may have very different energies in the deflectors than outside in the straight sections.

Possible improvements would consist of decreasing the non-linearities. At the moment it is not known whether these are due to the centrifugal term only, or if there are contributions from edge fields etc. The latter contributions could in principle be reduced, whereas the former is inherent in the machine with the very small radius of curvature.

REFERENCES

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