# ASTRID - A Small Multi-purpose Storage Ring

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*Abstract*

A small multi-purpose storage ring (40m circumference, 2 Tm rigidity) has been constructed at Århus University. It is being used as a heavy-ion facility for atomic physics and as a synchrotron-radiation source. Both positive and negative ions can be preaccelerated in an isotope separator and stored in the ring. Up to now, many different ions have been stored for experiments, e.g. $^{166}Er^+$,$^7Li^+$,$C_{60}^+$,$^4He^-$and $C_2^-$. The ion mode has been operational since the beginning of 1990.The electrons are preaccelerated in a 100 MeV race-track microtron. A maximum current of 132 mA has been accumulated and the first production run for synchrotron radiation will start in summer 1992.

## II. THE FACILITY

The motivation for the storage ring ASTRID first came from the wish to store low-energy ions for laser and recombination experiments. Later it was realized that the requirements for ion operation could be fulfilled by a storage ring which also could serve as a competitive VUV/XUV synchrotron-radiation source [1]. Hence a relatively expensive piece of equipment could serve a wider user community.

The layout of the storage ring with injectors is shown in fig. 1. The electron injector is placed in a separate well-shielded cave. There is no radiation shielding around the storage ring, and during filling of the ring with electrons, the ring hall is evacuated. Scrapers in the ring are left close to the electron beam to give a well-defined beam dump.

### *A. The injectors*

Ions are preaccelerated in an isotope separator using a very stable (RMS<1 V) 200 kV high-voltage supply. A variety of ion sources for both positive and negative ions can be used with the separator to produce singly-charged ions and molecules of almost any type. A charge exchange cell has been installed after the separator magnet to produce negative ions by electron capture in a Na, K or Cs vapour. Differential pumping in the injection beamline separates the high-pressure ion source ($10^{-2}$torr) from the storage ring vacuum ($10^{-12}$torr).

A pulsed (10 Hz) race-track microtron has been built to produce the 100 MeV electrons for the storage ring. The RF system is operating at 3 GHz. The resonant energy gain is 5.3 MeV corresponding to 19 turns.

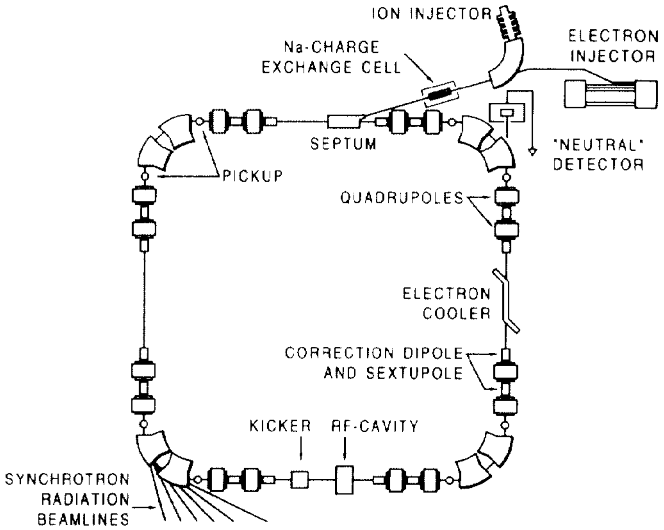

Figure 1. Layout of the storage ring with injectors.

### *B. The storage ring*

The "ring" is a square as formed by two 45° bending magnets, excited by a common coil, in each corner. The lattice functions for ASTRID are shown in fig. 2. The quadrupoles are grouped in four families, so that the dispersion in two opposite straight sections can be varied continously between 0 and 6 m without change of the tunes. In fig. 2 is shown the dispersion in ASTRID with four superperiods, and with two superperiods giving two dispersion-free straight sections.

Two families of 8 sextupoles are available for chromaticity corrections. Superimposed on the air-cored sextupoles are 8 horizontal and 8 vertical correction dipoles. Furthermore 4 horizontal correctors are available as back-leg windings on the main dipoles.

The vacuum system is designed for the $10^{-12}$torr region, as required for long storage times of the ions. Hence the system has been vacuum fired and is prepared for a 300° C in-situ bake-out. There is installed a total of 20 ion pumps and 24 sublimation pumps in the ring. Presently the system has only been baked to 150° C, resulting in an average pressure around $10^{-11}$torr.

Two different RF systems are used. For the ions, a

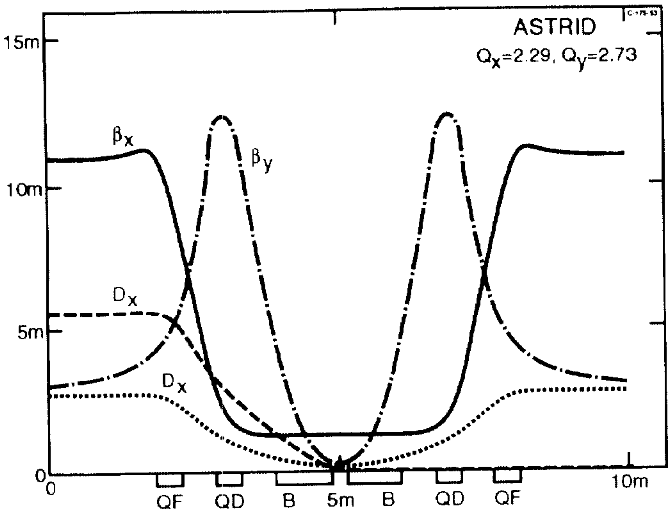

Figure 2. Lattice functions of ASTRID.

ferrite-loaded cavity operating in the 0.4-5 MHz region is available, giving a maximum voltage of 2 kV. For the electrons, a capacitively loaded coaxial TEM cavity operating at 104.9 MHz is used. This cavity was fabricated in steel, which was then copper plated. The obtained Q is around 9000.

Table 1
Parameters of ASTRID

| | | |
|---|---|---|
| general | | |
| Magnetic rigidity | | 1.87 Tm |
| Circumference | | 40 m |
| Hor., vert. tune | 2.29 | 2.73 |
| Hor., vert. chromaticity | -3.4 | -7.5 |
| Momentum compaction | | 0.053 |
| electrons | | |
| Nominal current | | 200 mA |
| Electron energy | | 560 MeV |
| Horizontal emittance | | 0.17 mm mrad |
| Critical energy, wavelength | 0.33 keV | 37Å |
| Energy loss/turn | | 7.1 keV |
| Beam lifetime (Touschek) | | 24 hours |
| Number of bunches | | 14 |
| RF system | 105 MHz | 125 kV |

Ions and electrons are injected with a magnetic septum (dc) and a kicker placed diametrically opposite. This configuration is ideal for a small ring where a local bump created by several kickers is often too space consuming and difficult to fit into the lattice. For the ions the electrostatic kicker excited by a square pulse injects one turn. For the electrons, a magnetic kicker excited by a half-sine pulse is used to accumulate electrons. The septum is also designed for extraction of a high-energy electron beam.

The kicker and RF-system are the only components being exchanged when swapping between electron and ion operation.

Clearing electrodes covering around half the circumference are installed in the ring to reduce ion-trapping effects.

A variety of diagnostics is installed, including 8 horizontal and vertical position pick-ups, scintillation screens, transverse and longitudinal Schottky pick-ups, beam-current transformer, beam scrapers and synchrotron-radiation detectors.

The control system is based on a NORD main computer with PC's as consoles. Autonomous function generators are used for all dynamical parameters for acceleration and similar operations.

## II. THE FIRST ION RUNS

Since the start up of the facility many different ions have been stored in the ring; a list is given in table 2.

Table 2
Ions stored in ASTRID

| | | | | |
|---|---|---|---|---|
| $^4He^+$ | $^6Li^+$ | $^7Li^+$ | | $^{20}Ne^+$ |
| $^{40}Ar^{++}$ | $^{151}Eu^+$ | $^{166}Er^+$ | | $^{12}C_{60}{}^+$ |
| $^3He^-$ | $^4He^-$ | $^9Be^-$ | $^{12}C^-$ | $^{12}C_2{}^-$ |
| $OH^-$ | $^{16}O^-$ | $^{19}F^-$ | $^{40}Ca^-$ | $^{56}Fe^-$ |

The stored ion beams had rigidities between 7 MeV/c for 6 keV $^4He^-$ and 260 MeV/c for 50 keV $^{12}C_{60}{}^-$.

The lifetime of stored beams of positive ions was limited by the vacuum, typically a few $10^{-11}$ torr, giving lifetimes around ten seconds. Stored currents for the positive ion beams were in the 1-10 µA range. Most of the runs with positive ions have been for laser cooling experiments [2].

The lifetime of a negative ion beam is determined by rest gas stripping, intrabeam stripping and field stripping (in the bending magnets) [3,4]. A new stripping mechanism has been identified for loosely

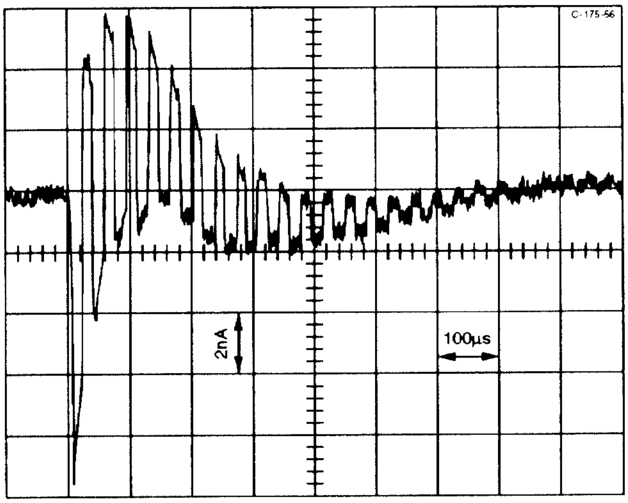

Figure 3. Decay of a 10 nA metastable $^4He^-$ beam.

bound ions. Black-body radiation can ionize ions with small electron affinities [5]. By heating the ring (usually used for bakeout) this stripping could be increased. Furthermore some ions are metastable and autoionize on timescales around a msec. In fig. 3 is shown the decay of a metastable 25 keV $^4He^-$beam as observed with a pickup. A storage ring, acting as a very long beamline, is ideal for such fundamental lifetime measurements.

Some negative ions can only be produced in small amounts, leading to currents in the pA-nA range. Hence they can only be observed with 'neutral' detectors monitoring the decay of the stored beam by counting neutralized ions at the end of the straight sections. An electron multiplier and a microchannelplate detector have been used in ASTRID for this purpose.

The observed closed-orbit deviations were less than 10 mm and could for $\mu$A ion-beams be corrected to less than 1 mm, limited by the position resolution.

The ion cavity has only been used at a fixed frequency to bunch the beam for life-time measurements.

## III. THE FIRST ELECTRON RUN

The 100-MeV race-track microtron has been commissioned and routinely delivers 10 mA pulses of 1 $\mu$sec width. A few turns of this 3 GHz beam are injected into the ring and captured by the 105 MHz RF system. The current captured per injection is around 1 mA, and the optimal injection rate is 1 Hz, to be compared to transverse damping times of 4 secs. During the commissioning it was realized, that beam loading in the rf-system [6] limited the maximum accumulated current to 1-2 mA per bunch for rf-powers of around 100 Watt. This limitation can not be cured by running with a much higher rf power. In our case a small rf power is needed to keep the bucket height smaller than the ring acceptance (1%) in order to have a good accumulation efficiency. Hence an amplifier feedback system was built, which reduce the effective cavity impedance as seen by the beam [6]. This provisional feedback system raised the accumulated current to 9 mA per bunch, probably still limited by beam loading. A feedback system with a larger gain is being built for the coming runs. The lifetime of this 132-mA beam at 100 MeV is 1-2 hours with the kicker on, which means that appreciably higher currents can be envisaged.

The horizontal and vertical chromaticity of the ring have been measured to -2.9 and -4.4, respectively, somewhat smaller than predicted by MAD (see table 1). Without chromaticity correction, the head-tail instability limit the current to around 2 mA/bunch. The coupling of the ring has been measured to 12% using the synchrotron radiation. Ion trapping effects have been observed, but they can be removed with the clearing electrodes. Only 20 mA has been accelerated to maximum energy, owing to the beam loading problems.

The position pick-up system designed for the heavy ions is also used to measure the closed orbit for the electron beam. This is done by mixing the 105 MHz signals from the beam with a local oscillator signal, to obtain a frequency of 11 MHz, which is below the bandwidth of the system (20 MHz). With this system, the closed orbit of the electron beam can be adjusted to around 0.1 mm.

## IV. FUTURE PLANS

The final step in the commissioning of the ion facility, namely acceleration, will be completed. The future runs will include $Mg^+$ and further $^7Li^+$runs for laser cooling. A program for Doppler tuned laser spectroscopy of $H^-$ is also under development. The electron cooler (electron target), which has been operational at the Tandem accelerator at the Institute of Physics for several years [7] is now being transferred to the ring. The physics aim is electron recombination/detachment studies using positive/negative ions and molecules.

It is planned that the electron/ion operation will alternate approximately every three months. The next electron run will comprise commissioning of the synchrotron-radiation facility to full specifications, i.e. 200 mA electron beam at 560 MeV. Several improvements will be added to the electron facility, in particular concerning the RF system. Three beamlines will be ready from the start, i.e. 1) a x-ray microscope, 2) a SGM monochromator operational in the 30-600 eV region for atomic physics and 3) a PGM monochromator (SX-700) for the 11-2300 eV range for surface physics.

Several longer term improvements are being discussed, among others we mention prebunching of the electron beam to increase the stacking rate and installation of insertion devices (wiggler/undulator) in the ring combined with new monochromators.

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