ASTRID, A STORAGE RING FOR IONS AND ELECTRONS

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The storage ring, ASTRID, presently being built in Aarhus, Denmark, is described. First the storage ring will be used in laser experiments using heavy ions of low charge state injected from a low-energy isotope separator. At a later stage, it is planned to turn ASTRID into a VUV synchrotron radiation source.

Introduction

After the successful commissioning of the first low-energy storage ring in the world, LEAR, discussions started at our institute about the usefulness of a storage ring for heavy ions, using the existing accelerators as injectors. It became clear, that the gains from a storage ring can be twofold in our case: either to increase the intensity of rare ions (in our case highly charged ions) or to increase the interaction time with ions. In the last case the storage ring acts as a very long beamline. To obtain a stored ion-beam current larger than available directly from our EN tandem it is, however, necessary to go to very high-energy highly-charged ions, because of intensity limitations on the stored beam. Later on, the idea was brought forward to use the storage ring for electons to produce synchrotron radiation. So the plan for the storage ring ASTRID is now first to use it to store low-energy ions of low charge state from a 200 kV isotope separator for laser experiments. Later on the synchrotron radiation facility will be added. Finally, the possibility to inject highly-charged ions from our tandem still exist.

The storage ring is situated in a recently constructed laboratory in connection with the Institute of Physics, see fig. 1.

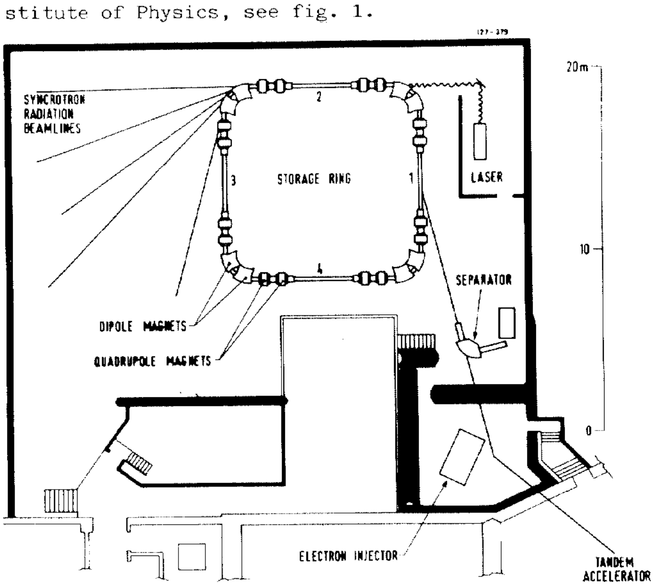

Fig. 1. Layout of the ASTRID laboratory.

Lattice

In the lattice-design, attention had to be paid to both the ion and the electron operation. Furthermore the number of magnetic elements had to be minimized to keep the circumference small. The chosen lattice is a separated function BODOFOFODOB lattice as in LEAR. The dipole magnets are sector magnets with perpendicular beam incidence. The lattice functions are shown in fig. 2. We have a large horizontal β-function in the straight sections to facilitate

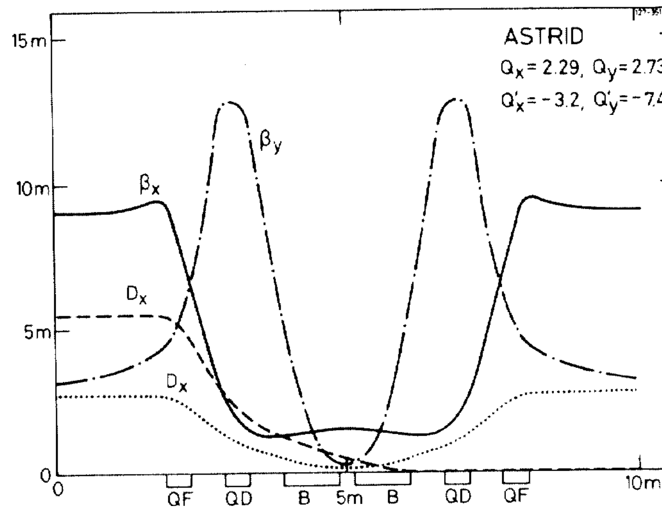

Fig. 2. Lattice functions for ASTRID.

injection. Both β-functions are small in the dipoles, to have a small synchrotron radiation light source (see later). The quadrupoles are grouped in four families, and the machine can be run with either two or four symmetric superperiods. The dispersion function for the four-superperiod lattice is shown in fig. 1 as the dotted line. By exciting the two focusing doublets on fig. 2 differently it is possible to vary the dispersion in two consecutive straight sections between 2.7 m to 0 m and 5.5 m, respectively, as shown by the dashed line. And this can be done without changing the tunes. The main parameters of ASTRID and the lattice with 4 superperiods are given in table 1. The horizontal tune

TABLE 1 Parameters of ASTRID

Magnetic rigidity	2.0 Tm
Momentum, ME/q^2	600 MeV/c, 163 MeV amu
Circumference	40 m
Dipoles: no, field	4x2, 1.6 T
aperture (good field); hor., vert.	$\pm$50(40), $\pm$ 32(22) mm
Quadrupoles: no, field	8x2, 6.7 T/m
mag. length	0.45 m
aperture, (good field)	$\pm$ 73(63) mm
Sextupoles: no, field	8x2, 10 T/m^2
mag. length	0.36 m
Corr. dipoles: no,	12+8
integrated field	0.007 Tm
Focusing structure	4 superperiods BODOFOFODOB
Hor., vert. tune	2.29, 2.73
momentum compaction	0.050
chromaticities	-3.0, -8.0
linear acceptances, hor.	320 π mmmrad
vert.	60 π mmmrad
momentum	$\pm$ 2.1 %

is close to 2.33 so that a 3rd order resonant extraction is possible. The natural chromaticities are fairly large for a proton ring but fairly small for an electron storage ring. Two families of 8 sextupoles each are installed for chromaticity correction. The straight sections (fig. 1) are reserved for: 1: injection/extraction and diagnostics, 2: experiment, 3: kicker, RF, diagnostics and 4: electron cooling.

Magnets

Dipoles: The sector-shaped dipoles have a maximum field of 1.6 T, and two 45° dipoles share two coils. The magnets will be individually shimmed to have $\int Bdl$ equal within $3 \cdot 10^{-4}$ over the good field region.

Quadrupoles: The quadrupoles have been shimmed by chamfering after which the scatter in the integrated gradient within each family is less than $\pm 3 \cdot 10^{-4}$.

Sextupoles and correction dipoles: 16 superposed dipoles and sextupoles of air core type with an iron shield are used. The sextupoles are connected in 2 families whereas the dipoles have individual power supplies. In addition to the 8 horizontal and 8 vertical correctors there are backleg windings on the main dipoles.

Injection/Extraction

To save space, we have chosen an injection scheme with only one kicker placed diametrically opposite to the septum. For the separator-ions both the septum and the kicker are electrostatic, but for the 100 MeV electrons from the injector microtron a magnetic septum and kicker will be built. A single turn injection will be used for the heavy ions, in which case the ions leave the septum at a small angle to the closed orbit. A multi-turn injection scheme with stacking will be used for the electrons.

Vacuum system

To have a long life-time against charge-transfer (minutes) of the slow ions we aim at a 10^{-12} torr vacuum. The vacuum system is thus made in stainless steel (316 LN), vacuum-fired and prepared for a 300° C in-situ bake-out. The pressure will of course be considerably higher when electrons are stored, due to photo-desorption from the walls by synchrotron radiation. We hope, nevertheless, to benefit from the clean vacuum system and the large pumping speed installed (20 ion pumps and 24 sublimation pumps) when storing electrons.

RF

We use a ferrite loaded cavity with a frequency range of 0.4-5 MHz for the heavy ions. The max. voltage per turn is 2 kV and the overall length of the cavity is 0.5 m. For the electrons a capacitively loaded coaxial TEM cavity operating at 104.9 MHz with a maximum voltage of 100 kV will be used. The length of this resonator is 1.1 m.

Diagnostics

The position of the beam is derived from 8 horizontal and 8 vertical position pick-ups. For the running-in 4 scintillation screens viewed by TV-cameras are available. One longitudinal and two transverse Schottky-noise pick-ups are installed. The pick-up plates for the transverse Schottky-detector are movable to have a large aperture during setting-up of the machine and to obtain a large transverse Schottky signal by approaching the plates close to the beam when operating. Furthermore excitation electrodes are installed upstream of the transverse Schottky pick-ups. Finally a beam-scraper is installed. A beam current transformer and synchrotronradiation monitor are foreseen for the electron operation.

e-cooling

Electron cooling is being considered for the ion-operation. To gain experience with an electron cooling device, an electron cooler has been built for a single-pass experiment at our Tandem. The aim is to study recombination processes, radiative, dielectronic and laser-induced, and this kind of study calls for the same qualities of the electron-beam as electron-cooling. The electron gun is a 10 mm diameter flat cathode Pierce gun with anode mesh and variable perveance. The electron energy range is 100-2500 eV with a current of 1-25 mA. The maximum solenoidal-toroidal field is 300 gauss.

Ion beam experiments - Laser cooling

The stored ions are injected from a 200 kV isotope separator. The beam from this accelerator has typically a transverse emittance of a few πmmmrad and an energy spread of a fraction of an eV. For these slow ions the space-charge limit the circulating current to a fraction of a µA. The very small momentum spread could give problems with the longitudinal microwave instability for this current just as the longitudinal part of intrabeamscattering is very strong.

The most interesting experiments for an accelerator physicist is probably the experiments or laser cooling[1]. The principle of laser cooling is shown in fig. 3. The ion moving with velocity v_o

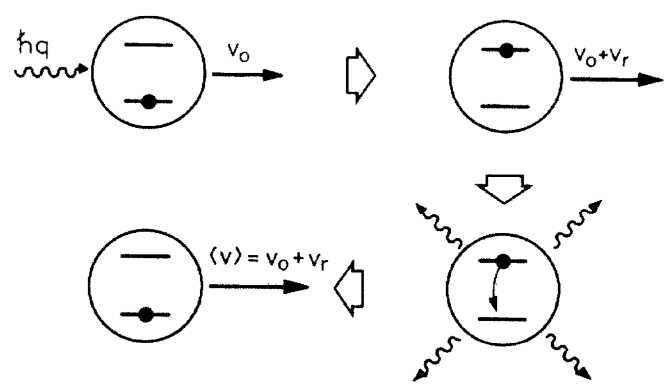

Fig. 3. Principle of laser cooling.

absorbs a photon of momentum $\hbar q$ whereby it is excited to it's upper energy level. The photon is spontaneously emitted in a random direction, and on the average the ion of mass M acquires a recoil velocity $v_r = \hbar q/M$ in each absorption and spontaneous emission cycle. Due to the Doppler shift of the laser photons only ions with a specific velocity can be excited by the photons. By scanning the laser frequency across the velocity profile of the ion beam, all ions can be left with the same velocity. The laser merely acts as a snowplough traversing the velocity profile leaving the ions with a much narrower profile at a slightly higher (or lower) velocity. Transverse cooling can also be performed by having the laser beam at a finite angle to the ion beam. Although the recoil kick from one photon absorption-emission is small, the cooling time can be made very small (10^{-4}-10^{-5} sec) due to the strong laserbeam and the small lifetime of the excited ions. The final temperature, corresponding to a single recoil, is also very small (10^{-2}-10^{-3} eV).

This cooling mechanism is clearly far from universal, since very few ions have an appropriate energy level scheme, but it is hoped to be useful in the generation of very cold beams. In these cold beams ordering, crystallization, will be important.

ASTRID as a VUV synchrotron radiation source

Electrons are injected from a 100 MeV racetrack microtron, now under construction, and a beam in the 100 mA region is accumulated in ASTRID before acceleration to the storage energy, max. 600 MeV. Parameters of the electron beam are given in table 2.

TABLE 2 Electron beam parameters

Energy	600 MeV
RF-voltage	100 kV
RF-frequency	104.9 MHz
Assumed x-z coupling	10%
Synchrotron radiation	9.2 keV/turn
Critical energy, wavelength	0.38 keV, 32 Å
Hor., ver., energy damping	23 msec, 17 msec, 8 msec.
Touschek lifetime at 100 mA	30 hours
Bunch length	3.1 cm
Emittance	0.16 πmmmrad
Beam size at entrance of dipole	0.44 mm, 0.29 mm
Beam div. at entrance of dipole	0.36 mrad, 0.06 mrad
Beam size in the middle of dipole	0.50 mm, 0.06 mm
Beam div. in middle of dipole	0.32 mrad, 0.27 mrad

The first synchrotron radiation beamlines will be for x-ray microscopy, atomic physics and surface physics.

Schedule

Most parts have been constructed and the storage ring will be assembled in 1988. A photograph from the ASTRID lab. from april this year is shown in fig. 4. The running in and first experiments will

Fig. 4. The ASTRID laboratory, april 1988.

start in the beginning of 1989 and last for approximately one year after which the running-in of the electron operation is scheduled. After the first synchrotronradiation run the two operation modes will alternate in periods of approximately 1/2 year.

Acknowledgements

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References

1. J. Javanainen et al., J.Opt.Soc.Am. 32 (1985) 1768.