CRYRING — A HEAVY-ION STORAGE AND SYNCHROTRON RING

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Introduction

CRYRING is a project aiming at a facility for research in atomic, molecular and nuclear physics using a cryogenic electron-beam ion source CRYSIS together with an RFQ linear accelerator as injector into a synchrotron-storage ring for very highly charged, heavy ions [1]. (CRYSIS stands for CRYogenic Stockholm Ion Source and CRYRING for CRYsis-synchrotron-storage-RING). The lay-out of a first phase of the planned facility is presented in Fig. 1. At the ring research programs on photon-ion, electron-ion and atom/ion-ion interactions will be possible over a wide range of relative energies and particle species. The quality of the beam of circulating ions will be improved by electron cooling.

In a second phase CRYRING will be equipped with a high-voltage (around 300 kV) ion accelerator as an alternative injector but also as the second source needed for atom/ion-ion collision experiments. An extracted beam is also planned for this phase.

CRYSIS

CRYSIS is an ion-source of a cryogenic EBIS type which has been built in close cooperation with the Institute de Physique Nucleaire in Orsay [2,3]. It has recently come into operation and is now used as a stand alone machine for low energy atomic collision physics research. The presently achieved data of the 1.6 m long confinement volume source is presented in Table 1. The source is still under a heavy development program aiming at higher intensities and charge states.

Table 1. Achieved data for CRYSIS

	Achieved	Design value	
Electron energy	12	50	keV
Electron current	0.1	3.5	A
Electron density	ca. 100	1000–10000	A/cm^2
Magnetic field (with ions out)	1–3	5	T
Ion intensity	3×10^9	3×10^{10}	ch./pulse
Pulse length	.05–20		ms
Charge states	Ar: up to +18 Xe: up to +44		

INIS

To improve the performance of CRYSIS an ion injector will be connected later this year. The injector will be an improved version of the system used at SATURNE [4], and is, in principle, a small isotope separator with an r=50 cm analysing magnet. Isotopically pure, singly charged ions can then be produced and via an inflection system be fed into the main ion source. The ion injection will allow the experiments at CRYSIS to be carried out with known charge states and known isotopes. In Fig. 1 is also demonstrated the areas dedicated to research programs using the ion-beam from CRYSIS as well as the beam from INIS (laser-ion interaction studies).

RFQ

A radio-frequency quadrupole linear accelerator is under construction and will be used as an injector to the ring, accelerating the heavy ions from CRYSIS (and possibly in a later phase also ions from the high-voltage accelerator) to an energy of 300 keV/u. The RFQ will be of the four-rod type developed at the Institut für Angewandte Physik in Frankfurt/M. It is reported to this conference in a separate contribution [5].

The RING

The main parameters of the ring are summarized in Table 2. The Lattice [6] will have six superperiods as demonstrated in Fig. 1.

Table 2. Main parameters of CRYRING

Circumference	51.63	m
Q_x	2.30	
Q_y	2.27	
$\Delta Q_x/(dp/p)$	−1.3	
$\Delta Q_y/(dp/p)$	−3.2	
ϵ_x at inj.	200π	mm·mrad
ϵ_y at inj.	100π	mm·mrad
$\Delta p/p$ at inj.	$5 \cdot 10^{-3}$	
$\beta_{x,max}$	6.3	m
$\beta_{y,max}$	6.5	m
$D_{x,max}$	2.1	m
E_{inj}	0.3	MeV/u
for $q/A < 0.25$	0.3 q/a	MeV/u
E_{max}	$96(q/A)^2$	MeV/u

No focusing elements will be placed in six ofthe twelve straight sections. Out of these, three are used for injection, RF cavity and electron cooling. The remaining three will be used for beam diagnostics and experimental set-ups, and (in phase 2) for extraction. The small variation in the beta-functions is offering a special feature to some experiments planned for the ring.

Magnets and Power Supplies

The main magnet data are collected in Table 3.

The dipoles are built up from 1.5 mm laminations and are giving a 30 degree bend each. The useful area of the field is increased with minor Rose-shims and the entrance and exit edges have Rogowski contours. In order to get more space the coils are removed from the central plane and are mounted at a distance of 200 mm from each other. The laminations for the quadrupoles are being punched in one piece in order to improve the symmetry of the field. The pole ends are cut at an angle of about 45 degrees.

Table 3. Magnets

Dipoles		
number	12	
bending angle	30°	
bending radius	1.2	m
gap height	80	mm
max field	1.2	T
beam aperture	55 × 100	mm^2
Quadrupoles		
number	18 (12QF, 6QD)	
aperture	125	mm
eff. length	0.3	m
max field grad	5.0	T/m
beam aperture	100	mm
Sextupoles		
number	12	
aperture	125	mm
eff. length	0.2	m
max field par	12	T/m^2
beam aperture	100	mm

The influence of the vacuum chamber walls due to eddy currents at the fast ramping has been carefully calculated. The heating of the chambers calls for cooling [7].

Correcting dipoles have been calculated and a prototype will be tested before the mechanical design is settled. Extra laminations of the quadrupoles are purchased to be used for skew quadrupoles.

The design of the dipole and the quadrupoles power supplies allows the possibility of running the ring in a fast ramped mode of up to about 7 T/s. This will have positive implications for many scientific programs discussed, offering high duty-factors particularly when running the ring with ions that have a high loss rate in the storage mode.

UHV-system

In storage mode CRYRING is supposed to operate at a pressure of 10^{-12} torr in the ring [8]. Originally this goal was planned to be achieved with a number of ion pumps and titanium sublimation pumps. However, the possibility of replacing the TSP:s with NEG pumps has been studied and found possible, at least for pressures down to 5 ptorr. Special care has to be taken at several points in the machine, at injection and cooling, e.g., where extra pumping capacity will be needed. Also between the RFQ and the ring, differential pumping has to be applied to reduce the pressure by several orders of magnitude. The UHV technique has been studied in different model experiments comprising a section of the ring.

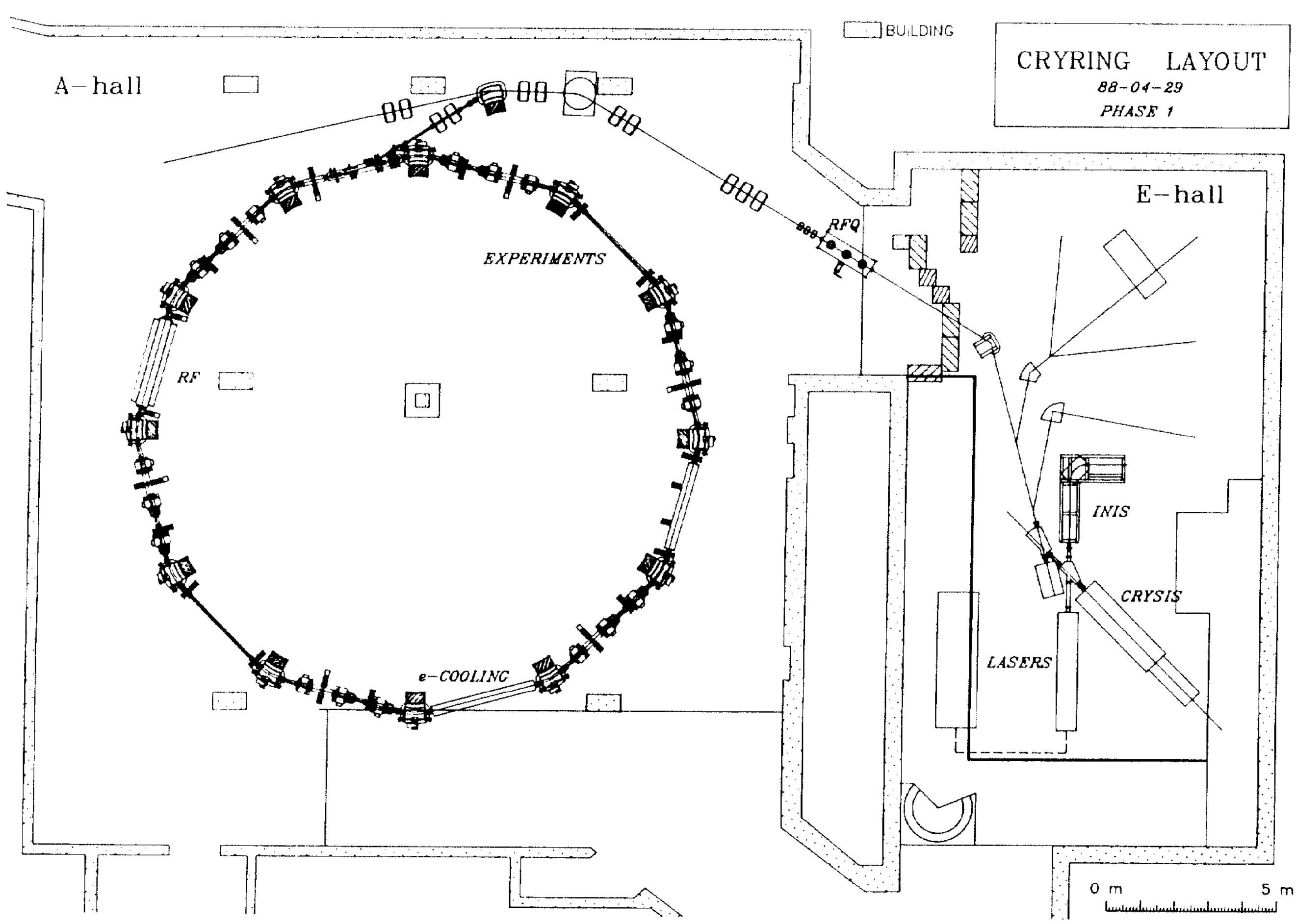

Fig. 1. Lay out of CRYRING.

Injection

The beam pulse from CRYSIS is expected to be 40–50 microseconds long, which implies a multiturn injection into the ring over 8–10 turns. The electrostatic injector and beam displacement plates are presented in a special report to this conference [9].

Acceleration system

CRYRING is expected to work in a very wide energy range, from 0.3 to around 24 MeV/u, corresponding to a frequency span of about 8. In the future, moreover, ions will also be injected directly from the 300 kV electrostatic accelerator, giving ions with a lower energy per nucleon. For a first harmonic bunching and accelerating cavity, this means an even higher frequency span. Since the circumference of the ring is relatively small, the possibility of using a non-resonant driven drift-tube has been studied. A model cavity has been built and studied in detail up to drift-tube voltages of 600 V and a frequency range of 10 kHz to 1.5 MHz [10].

Electron cooler

The electron cooler being designed for CRYRING [11] will serve two purposes: improve the beam emittance and provide an electron target for atomic-physics experiments. The maximum ion energy of 24 MeV/u ($Z/A = 0.5$) corresponds to an electron energy of 13 keV but when the cooler is used as electron target the energy can be increased to 20 keV. With full emittance of the ion beam the optimal cooling rate is obtained.

DIAGNOSTICS

CRYRING will be equipped with different diagnostic elements to determine the beam position and profile [12]. In the beam lines outside the ring destructive beam-profile monitors will be used. Each one of these consists of an Al_2O_3 disk onto which 32 gold strips are evaporated. The measuring points will have two such detectors each for measuring the beam size in x and y direction, respectively.

In the ring electrostatic beam pick-ups will be used as the main tool for diagnostics. Eight pairs of such detectors are planned around the ring mainly to be placed in the straight sections containing the focusing magnetic elements. The electronic systems like preamplifiers, amplifiers, multiplexor, ADC and a VME computer system are being tested.

As a complement to the electrostatic detectors a Schottky-noise pick-up is planned to be included in one of the free straight sections. The signals will be analyzed in a spectrum analyzer. Also, a fast fourier transform (FFT) program has been acquired for the separate diagnostic computer system, which will be controlled from the main control system computer.

CONTROL SYSTEM

The control system for CRYRING [13] is in all essential parts a copy of the CERN-LEAR control system. It is built in three hierarchic levels mainly consisting of:

a. A central computer (PDP 11-73) with operating console

b. A CAMAC-based data-distribution system

c. About one hundred micro-processors for direct control of the different systems.

Level a. and part of level b. are already in operation using a copy-transcription of the LEAR software program. The program for the static parts of CRYRING is operational, whereas the parts needed for the dynamical (fast ramping) controls still are under development. It is planned to have CRYSIS and its injector INIS as the first parts connected to the control system in 1988.

FUTURE PLANS

The plans for the next two years comprises the building of different components and subsystems mounting of the equipment, and — hopefully — starting-up phase 1 of the system in 1990.

After 1990 mainly two development programs are foreseen for a second phase: An extraction system using a third order resonance regime and the introduction of a 300 kV electrostatic ion-accelerator. Extraction of the beam from CRYRING aims mainly at different experiments using very heavy ions impinging on solid targets. The electrostatic accelerator will serve two purposes. It will be a second injector used for light ions (q/A larger than 0.25), and for low charge-state heavy atomic and molecular ions (q/A less than 0.25). It will also be a source for ion-beams used in collision experiments with the CRYRING beam in crossed and merged beams.

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