Status of the CRYRING project

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Abstract—The status of the CRYRING project is reported. Results of the tests that began with the first beam in December 1990 are reviewed.

Introduction

This report summarizes the present status of the CRYRING project [1]. The project is centered around a synchrotron/storage ring of maximum rigidity 1.44 Tm, corresponding to an energy of 24 MeV per nucleon at a charge-to-mass ratio $q/A = 0.5$. It is mainly intended for highly charged, heavy ions produced by an electron-beam ion source (CRYSIS). Light atomic or molecular ions can also be injected from a small plasmatron source (MINIS). Ions from the ion sources are accelerated electrostatically to 10 keV per nucleon and transported to a radiofrequency-quadrupole linear accelerator (RFQ) which brings them to 300 keV per nucleon. The ions are inflected electrostatically into the ring where they are accelerated using a driven drift tube. The stored ions will be cooled by an electron cooler. Fig. 1 shows a layout of the CRYRING facility.

Ion sources

For the ring and RFQ tests performed so far the MINIS plasmatron ion source has been used. This source was originally intended for the initial tests only but will in an upgraded version also be used to run molecules and some light ions such as Li^{+} for laser cooling. It will be provided with an analyzing magnet and will be made completely UHV compatible.

The CRYSIS electron-beam ion source [2], which gave the first beam to low-energy experiments in 1987, has since been continuously modified and improved. Electron-beam currents up to 250 mA have been propagated through the source. Typically currents of about 125 mA are used to produce highly charged ions up to Ar^{18+} (3×10^{6} ions per pulse) and Xe^{44+}. The ion output has been stable during shifts lasting over 12 hours and changing between xenon and argon ions requires only a few hours. Recent work on the source has included a raising of the capacity of the liquid-helium system, implementation of full computer control of the source parameters, and insulation of

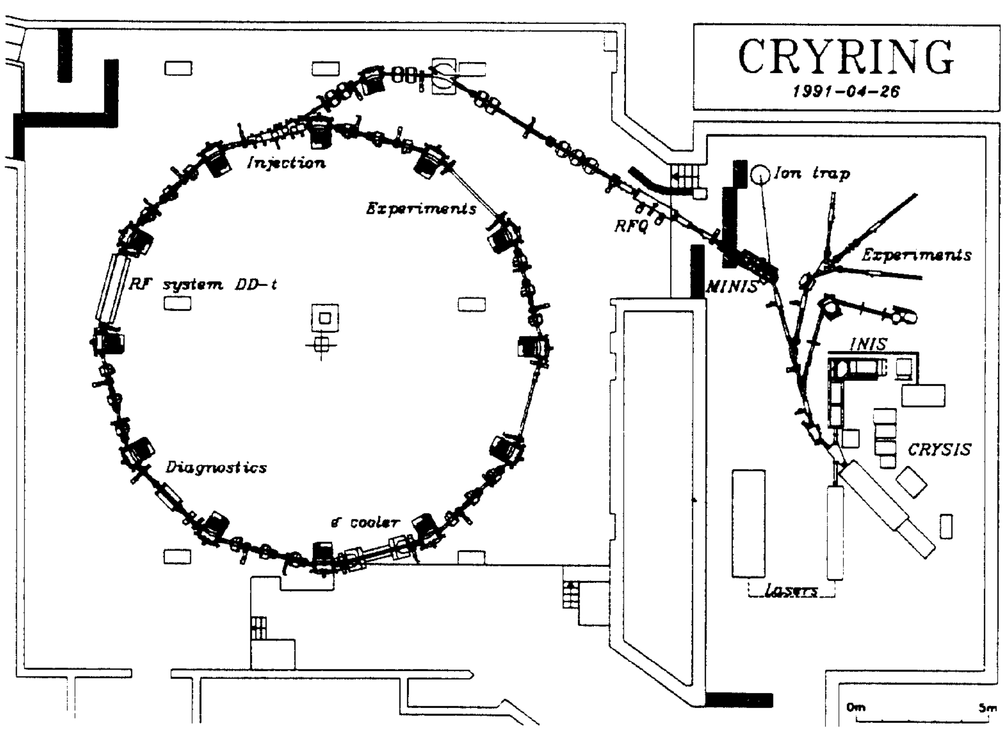

Fig. 1. Layout of the CRYRING facility.

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the entire source, including helium liquefier, for 50 kV as a preparation for injection of CRYSIS ions into the ring. The beamline connecting CRYSIS with the RFQ will be completed during the summer of 1991 and then tests with heavy ions in the ring will begin.

RFQ

The RFQ [3] has been used with an RF power of up to 30 kW and has successfully accelerated ions with $q/A \geq 0.33$. Due to the 30-kW limitation particles with lower q/A have not been used. The transmitter will, however, shortly be upgraded to deliver a pulsed RF power of 100 kW. Optimizing the low-energy (10 keV per nucleon) transport line to the RFQ has been difficult due to a mixture of ions in the beam from MINIS. This problem will be relieved when MINIS is rebuilt and an analyzing magnet has been installed or when CRYSIS ions are used.

Ring

The ring has so far been operated with dipole and quadrupole magnets only. Correction dipoles are ready for use but have not been needed yet—a first closed-orbit measurement at injection energy showed deviations of less than 10 mm. Sextupole magnets are mounted in the ring but their power supplies are not purchased. In the runs so far the regular working point of $Q_x = 2.30$ and $Q_y = 2.27$ has mostly been used but a higher working point with $Q_x = 3.4$ and $Q_y = 1.8$ has also been tried successfully.

The power supplies for dipole and quadrupole magnets have operated at DC currents for most of the runs but tests of the fast ramping (150 ms ramp time and 500 ms cycle time) have been performed and all data concerning stability, time response, etc. were found to lie within the specified values. The power supply for the electron cooler magnets has also been tested with a satisfactory result.

Since the injection energy from the RFQ is as low as 300 keV per nucleon the inflection of the injected ions and the closed-orbit displacement are made electrostatically [4]. The displacement is made locally, making the injection less sensitive to the choice of working point. The four pairs of plates displacing the orbit at injection are supplied by a single high-voltage supply with one positive and one negative output that is ramped from ±30 kV to zero in 50–100 μs. This allows for a multiturn injection over about 10 turns which has been used all through the test of the ring. The fields between the plates can be adjusted by changing the distances between them using stepper motors.

The acceleration system, a driven drift tube [5], currently operates over its main frequency range (<150 kHz to 1.5 MHz) up to a peak-to-peak voltage of 1 kV, both at constant and ramped frequency, using a surplus test power tube. The full design voltage of 7 kV peak to peak, needed for fast acceleration of particles with low q/A, will be achieved after switching to a full-power tube already in house. To allow for bunching and acceleration of slow, low-charge ions such as molecular ions, the RF system has been designed to work at frequencies down to 10 kHz. This feature has been shown to work but is not yet fully operational.

The magnetic field in the electron cooler [6] has been measured using Hall probes for rough scans through all magnets and an electronic autocollimator for precision measurements of the straightness of the field in the cooling solenoid. Based on the results of the autocollimator measurements two sets of correction coils were made. As a result a field straightness of better than ±0.1 mrad was achieved. The vacuum system, the gun and the collector is under manufacturing and we plan to install the cooler in the ring at the end of 1991.

The pressure in the ring is at present a few times 10^{-9} torr, maintained by twelve ion pumps with a total pumping speed of 1000 l/s. During the early autumn of 1991 60 NEG-pump modules, each one containing 2700 cm^2 NEG strips, will be installed. This is expected to reduce the pressure by about a factor of ten. The UHV system has not yet been baked although all critical components such as dipole and quadrupole chambers are fully prepared for bake-out.

Nine horizontal and nine vertical pickups are in use in the ring. The signals from these pickups can be processed either by a fast peak-detection system [7] or using synchronous rectifiers for low-bandwidth measurements. A system with flash ADCs for Q-value measurements over 128 turns is also under construction. A Schottky-noise detector consisting of four plates 135 cm long and 9 cm apart has been assembled and tested.

The first parts of the control system, controlling CRYSIS and its ion injector INIS have now been in use for two years. The different subsystems of the ring, such as beam lines, RFQ, injection, ring magnets and the acceleration have successively been connected to it. Local control of subgroups of parameters has been implemented using terminal stations with limited menues.

Results

The initial tests of the RFQ and the ring have been performed using the MINIS ion source and light ions such as H_2^+, D^+ and $^3He^+$. These beams have been accelerated through the RFQ and injected into the ring using multiturn injection over 10 turns. During the first runs about 1×10^9 H_2^+ ions were stored, later that number was increased to 1×10^{10}. The D^+ current was somewhat smaller than the H_2^+ current since the ion source gives smaller amounts of atomic ions than of molecular ones. Also the transmission through the RFQ has not been fully optimized for all ions run so far.

The half-life of the H_2^+ beam was only ten milliseconds due to the large dissociation cross section at the injection energy of 300 keV per nucleon. The residual-gas pressure was around 2×10^{-9} torr. Running with D^+ the lifetime was increased and the beam has been seen for more than two seconds. In this case the lifetime is probably limited by multiple scattering although an exact calculation is difficult due to the uncertainty in rest-gas pressure and composition.

During most of the runs the beam was bunched by an RF voltage of constant frequency and amplitude applied to the acceleration drift tube. The beam was then followed through the sum signal from one of the electrostatic position pickups. Fig. 2 shows a measurement during the injection phase with the beam of H_2^+ building up during the multiturn injection, getting bunched and decaying. Adiabatic trapping has also been used, leading to a considerable increase in the trapping efficiency. The lifetime of the beam was measured by monitoring the amplitude at the revolution frequency of the above beam signal as a function of time. Such a measurement for D^+ ions is shown in fig. 3.

The ramped operation of all parameters used during acceleration has been implemented and gradually tested. In a first step, the week before this conference, a D^+ beam was accelerated from the injection energy to 350 keV per nucleon and followed for one second at the higher energy.

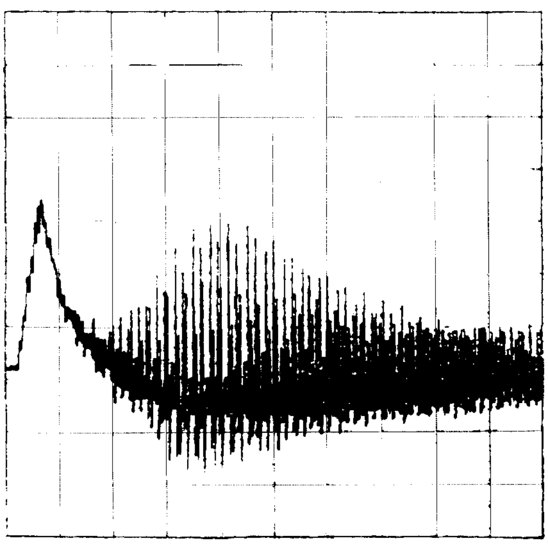

Fig. 2. Signal from H_2^+ beam. Sweep time is 1 ms.

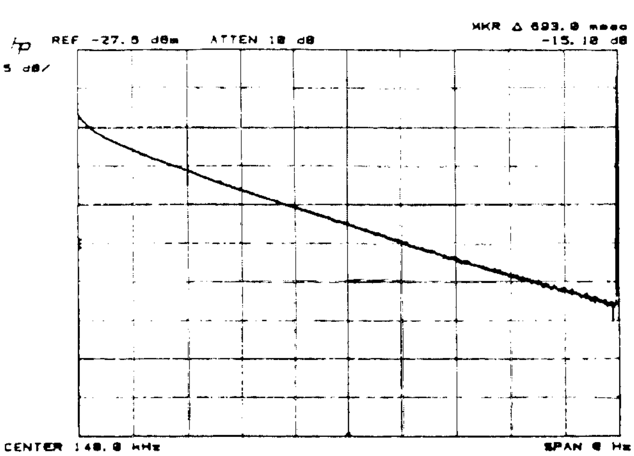

Fig. 3. Signal from D^+ beam. Sweep time is 1 s.

Experimental program

The first experimental device to be inserted into the ring will be a residual-gas-ionization detector. This system will allow the measurement of the position and profile of the stored beam through the coincident detection of recoil ions and electrons from ionization events. A resolution of better than 100 μm is expected.

After installation of the electron cooler during the autumn of 1991 experiments using the cooler as an electron target will start. These will include studies of dissociative recombination at very low relative velocities of light molecular ions such as H_3^+ or HeH^+ and x-ray spectroscopy of radiative recombination into highly charged ions. Also experiments on laser cooling of Li^+ and Be^{2+} are being prepared.

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