NEW INJECTION AND EXTRACTION AT CRYRING FOR FLAIR*

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Abstract

As a preparation for a future transfer of CRYRING to FLAIR at FAIR in Darmstadt, Germany, we have installed and tested a slow extraction system. (FLAIR is a low energy part of FAIR.) At FLAIR CRYRING will be used for deceleration of antiprotons from 30 MeV to 0.3 MeV. The tests of the slow extraction show that the beam can be extracted during 2 s with 30-60% efficiency and with rather constant amplitude, apart from 50 Hz harmonics. Fast extraction will also bee included in the installation at FAIR, but has not been tested.

A new injection system has also been designed. It will be able to inject two very different beams, 30 MeV antiprotons from NESR as well as 0.3 MeV H^- or protons created in a separate ion source and accelerated in an RFQ. The low energy ions will be used to set up and test the ring.

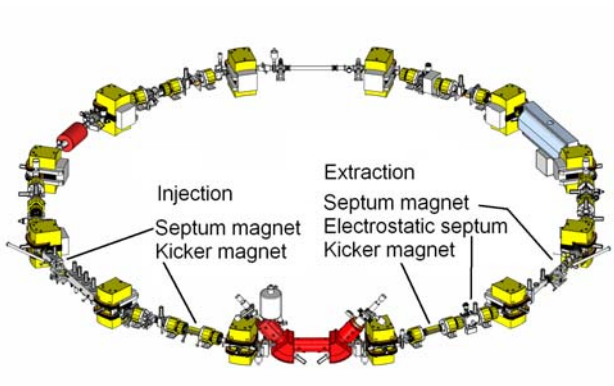

Figure 1: New hardware for injection and extraction.

INTRODUCTION

CRYRING is a 52 m circumference synchrotron and storage ring at Stockholm University, which presently is being dismounted. It will later be shipped to the FAIR project in Darmstadt [2] where it will be converted to the LSR, Low Energy Storage ring, and used to decelerate antiprotons and heavy ions. In this article we describe the necessary modifications of the injection and the new extraction system. A much more detailed description of CRYRING and its adaptation to FLAIR is found in the LSR technical design report [1].

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KICKER AND SEPTUM MAGNETS

The ring will be equipped with two new septum magnets and two new kicker magnets for injection and extraction respectively. The data will be very similar for the two pairs, since injection will be at maximum energy and extraction is planned over the full energy range.

The kicker magnets with supplies based on semi-conductor switches have been ordered from Sigmaphi, ceramic vacuum chambers from Kyocera, and the septum magnets from Danfysik.

Table 1: Septum Magnet Specifications

Maximum field	0.33 T
Length	683 mm along the arc
Deflection	16.8°
Gap (H × V)	80 × 38 mm^2
Wire	6 turns, 5 × 5 mm^2

Table 2: Kicker Magnet Specifications

Maximum field	0.048 T
Length	400 mm
Rise/fall time	280 ns
Deflection	20 mrad (1.1°)
Gap (H × V)	87 × 107 mm^2

INJECTION

Ten turn multiturn injection of 0.3 MeV H^- or protons need to be combined with single turn injection of 30 MeV antiprotons. The low energy system is similar to the one used in CRYRING, with four pairs of electrostatic kickers in the injection section, powered by one power supply. To enable injection of high energy antiprotons the electrostatic bend and septum are replaced by a septum magnet and two small bends, as shown in Figure 2. The high energy ions are not affected by the electrostatic elements but put on orbit with a kicker magnet in the next section, see Fig. 1. Data for the magnets are given in tables 1 and 2.

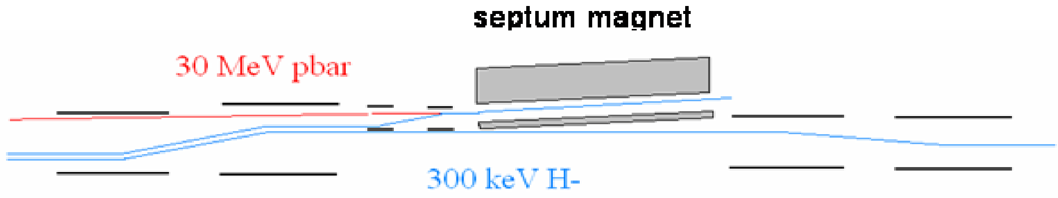

Figure 2: Bird's-eye view of the injection section. The path for single-turn injection of 30 MeV antiprotons is shown in red and the one for multiturn injection of 0.3 MeV protons in blue. The transverse scale is exaggerated for clarity. From left to right, two electrostatic kickers, two small electrostatic bends, septum magnet, two pairs of electrostatic kickers. Electrostatic elements are for slow ions only.

Multiturn Injection

Injection of low energy ions will be used for tests of the ring and experiments with extracted beam. 10 turn multiturn injection during 70 µs will be used to get a good intensity. During this time the voltage on four pairs of plates will go to zero. Simulations [1] show that the efficiency will be around 70% for a beam with 5 π mm mrad and ±1% momentum spread. The losses are mainly ions with large momentum which hit the septum due to dispersion. Losses during RF capture are not included in the calculations. The large momentum spread is created by the RFQ.

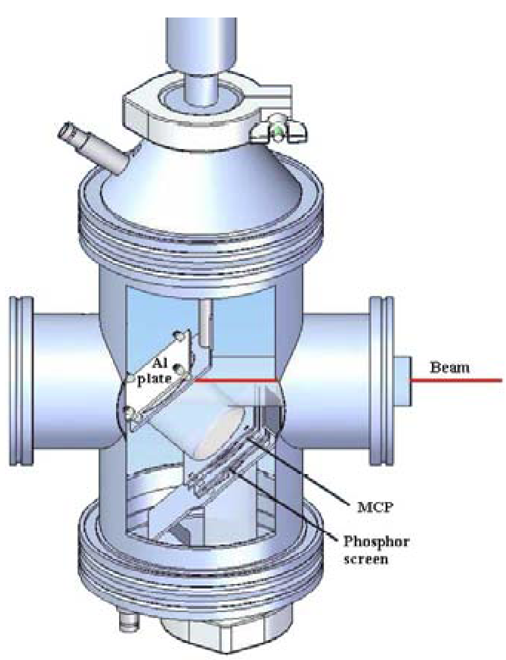

Figure 3: Drawing of REX-type beam viewer, where the beam comes in from the right, hits an aluminium plate and produces electrons that are amplified by MCPs and detected on a phosphor screen.

EXTRACTION

It should be possible to extract from LSR over the full energy range, i.e. 0.3-30 MeV protons, antiprotons and H^-, or other ions with the same magnetic rigidity.

The extraction system has three new components: a fast kicker for the single turn extraction, an electrostatic septum for the resonant extraction, and a magnetic septum which is common for both types of extraction. In addition sextupole magnets and a white noise kicker are used for the resonant extraction.

Slow Extraction

Slow extraction was included in the initial plans for CRYRING, but it was never implemented. However, the ring is equipped with twelve sextupole magnets so the resonance Qx=2.333 can easily be excited. The tunes normally used are Qx=2.43, Qz=2.44, but for extraction one needs to start below the resonance and Qx=2.32 was used in the tests described below.

There is no beamline for an extracted beam in CRYRING, but an electrostatic septum was installed for the extraction tests. A so called REX-viewer in the straight section following the electrostatic septum, was used to detect ions which have jumped over the septum and been deflected away from the circulating beam. The viewer was placed in almost the same position as the future septum magnet. A schematic drawing of the REX-viewer is shown in figure 3 and it is described in detail in the references [3, 4]. It monitors the transversal beam shape by detecting the secondary electrons that are ejected from an aluminium plate when it is hit by the beam particles. In our case the image of the beam was used to find the extracted beam, and the pulses from the MCP were sent to a counter to obtain the number of ions on the detector plate. The viewer was mounted on an actuator so it could be positioned outside the circulating beam, where it was hit by the ions that had been deflected 25 mm by the electrostatic septum field.

White noise was used to move the ions outwards. Noise with the amplitude ±60 V on a 75 mm long kicker with 55 mm gap killed the beam in 2 s, and when the resonance was exited with a sextupole magnet the extracted beam could be seen on the REX-viewer.

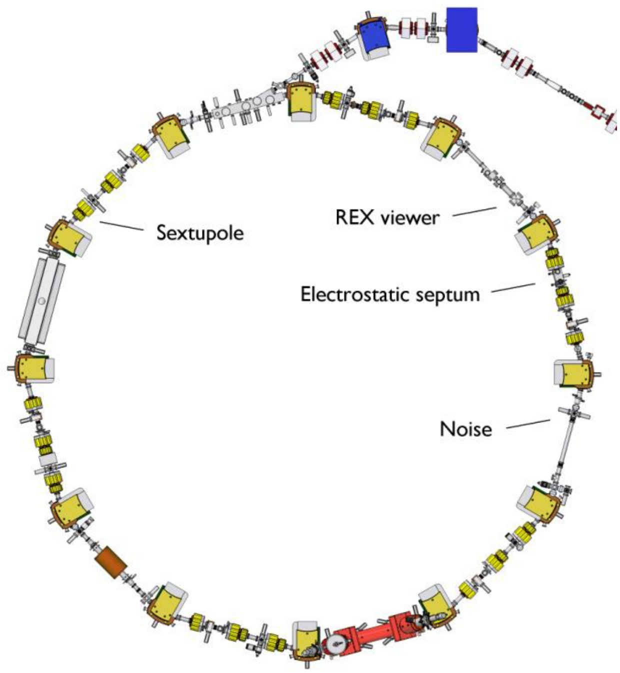

Figure 4: Hardware used for the tests of slow extraction.

Measurements of Slow Extraction

The following beam cycle was used in the tests:

- injection and acceleration to 3 MeV/u
- electron cooling for 5 s
- resonance excited with one sextupole
- extraction; beam blow-up with RF noise for 2 s

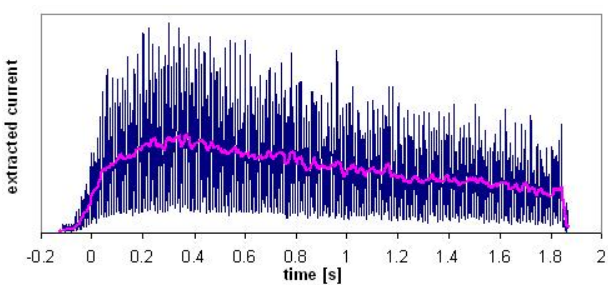

Figure 5: Extracted beam current, the pink line is the current averaged over 20 ms, i.e. without 50 Hz harmonics. All elements are static during extraction. The noise is caused by ripple on the supplies for the main quadrupoles and dipoles.

The antiproton beam that will be injected into LSR is expected to have very small emittance, so electron cooling makes the beam similar to what is expected.

In Fig. 5 the time structure of an extracted beam is shown. The efficiency of the extraction is estimated to 30-60%, depending on the secondary-electron yield when ions hit the Al plate of the detector. This is less than one would hope for during production, but we only had a limited time for the tests. There is room for more careful optimizations of e.g. the alignment of the electrostatic septum. Nevertheless, the tests have successfully demonstrated slow extraction in CRYRING.

A remaining problem is the large oscillations of the extracted current. As can be seen in Fig. 6, the noise is caused by 50 Hz harmonics. These are caused by the main magnet supplies, and most critical is the ripple on the focusing quadrupoles.

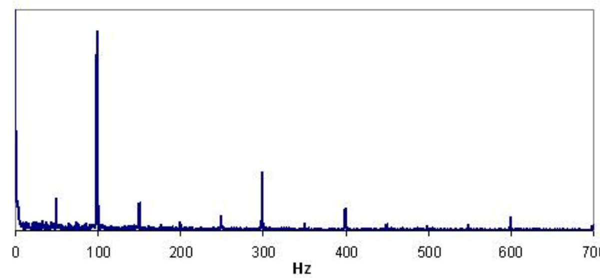

Figure 6: FFT of the beam current in the previous figure, 100 Hz and 300 Hz are the strongest components.

We have not made any work to reduce the oscillations of the extracted beam current, but simulations [1] show that most of the 50 Hz harmonics on the extracted current can be compensated with a fast dipole correction element. In addition a closed control loop for the noise amplitude has been demonstrated in HIT [5], and can remove slow variations of the current.

REFERENCES

[1] LSR Technical Design Report, www.msl.se/flair/DesignReportLSR_1.3.pdf (2011)
[2] www.fair-center.org
[3] K. Kruglov et al., Nucl Inst Meth A 441 (2000) 595.
[4] K. Kruglov et al., Nucl. Phys. A 701 (2002) 193.
[5] A. Peters et al, MOPEA006, IPAC'10