THE COLLECTOR RING CR OF THE FAIR PROJECT*

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Abstract

The Collector Ring is a storage ring in the complex of the FAIR project. It has the purpose of stochastic precooling of both rare isotope and antiproton beams and of measuring nuclear masses in an isochronous mode. The paper discusses progress in the development of magnet systems, rf systems, injection/extraction strategies and stochastic cooling systems.

OVERVIEW

In the framework of the GSI FAIR project, the main purpose of the CR storage ring is stochastic precooling of both antiproton (pbar) and secondary rare isotope (RI) beams. Furthermore it will be used for mass measurements of short-lived RI beams in an isochronous mode, which means that the ring is operated at transition energy [1]. The maximum magnetic rigidity is 13 Tm, the circumference is 210.451 m.

The CR is housed in a common building with the RESR [2], the accumulator ring for antiprotons. Its beam plane lies 1.2 m below the one of the RESR, 1.3 m above ground floor level. Seen from above, its beam orbit is situated roughly 3 m within the RESR beam orbit. Therefore the beam line connecting both rings has both horizontal and vertical deflector magnets. Its optics is based on an achromatic design.

Table 1 displays the beam parameters before and after cooling. The beam quality of the extracted antiproton beam is sufficient for effective accumulation in the RESR ring. RI beams are extracted into the RESR, where they are eventually decelerated without cooling. The next cooling step for the ions is electron cooling in the following NESR ring [3]. The very demanding cooled beam quality in the CR stems from the requirement of sufficiently fast electron cooling in the NESR.

The ion optics of the CR was designed for optimum performance of the following subsystems:

- a full aperture injection system
- an rf system for bunch rotation and adiabatic debunching after injection as well as rebunching after cooling
- common stochastic cooling systems for both antiproton and RI beams

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Table 1: CR beam parameters

	pbars	RI beams
kinetic energy	3 GeV	740 MeV/u
particle velocity	0.97 c	0.83 c
max. no. of particles	10^8	10^9
momentum width after injection	$\pm 3\%$	$\pm 1.5\%$
momentum width (2σ) after debunching	0.7 %	0.4 %
momentum width (2σ) after cooling	0.1 %	0.05 %
emittance (x and y) after injection	$240 \cdot 10^{-6}$ m	$200 \cdot 10^{-6}$ m
emittance (2σ, x and y) after cooling	$5 \cdot 10^{-6}$ m	$0.5 \cdot 10^{-6}$ m

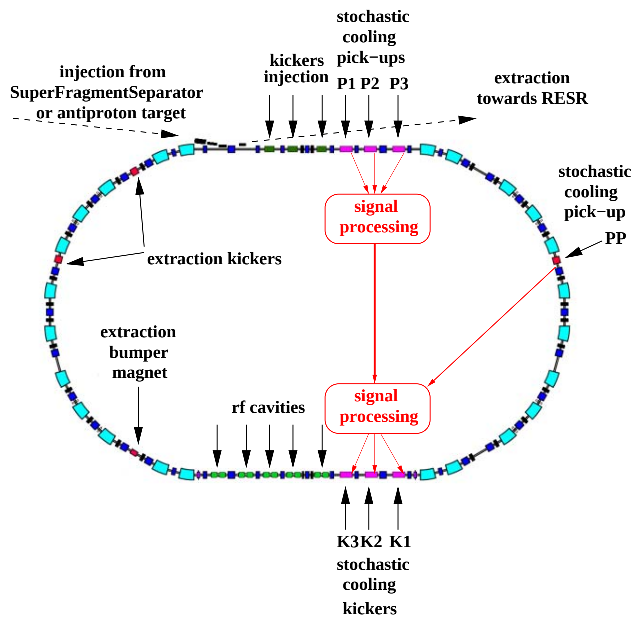

Figure 1: Layout of the CR with stochastic cooling lines.

- fast extraction systems of the cooled beam towards the RESR

Figure 1 sketches the layout of the CR. The CR lattice consists of two large arcs and two long straight sections. As a basic principle, the straight sections are dispersion free. For more details, we refer the reader to [4], [5], and [6].

MAGNET SYSTEMS

All CR magnets are operated exclusively in dc mode. However, their polarity can be reversed within 300 s, in order to facilitate switching between antiproton and RI beam operation. Both superconducting and normal conducting technologies are adopted.

The 24 CR dipole magnets are H-type superferric magnets with a large useful aperture of $380\text{mm} \times 140\text{mm}$. Their effective length is 2.126 m. Good field quality is required for field levels in the range $1.2 \cdots 1.6$ T. Due to the choice of a large number of coil windings, the inductance (36.8 H) of each magnet is rather large, but the maximum current (178 A) is moderate. This design minimizes heat losses in the current leads. Each dipole magnet is equipped with correction windings for horizontal beam orbit correction. A collaboration with a Chinese consortium led by the IMP institute at Lanzhou in China has been established which develops the design of the CR dipole magnets.

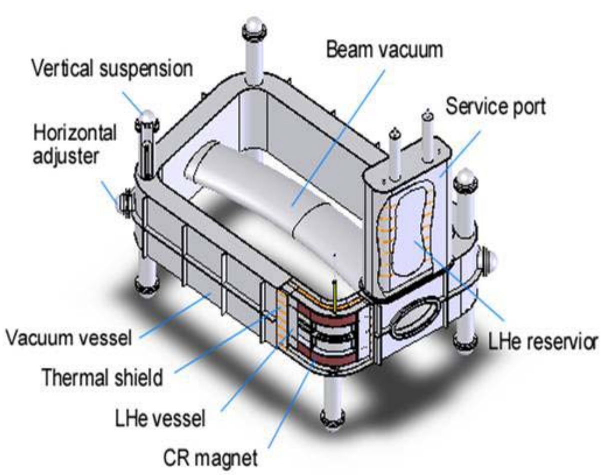

Figure 2: Sketch of CR dipole with cryogenics.

Two different designs are foreseen for the normal conducting CR quadrupole magnets, a wide and a narrow configuration. Which one will be used depends on the aperture requirements, which are more demanding in the arcs than in the long straight sections. 30 wide and 24 narrow quadrupoles are foreseen. Some of their parameters are listed in Table 2.

Mainly for chromaticity correction, 28 sextupole magnets and 16 octupole correctors are foreseen. Beam orbit correction is important for an optimum performance of stochastic cooling. Hence, in addition to the correction windings mentioned above, there will be 4 lumped horizontal orbit correctors in the long straight sections, as well as 14 lumped vertical steerers distributed all over the ring.

Table 2: Quadrupole magnet parameters

quadrupole type	wide	narrow
no. of magnets	30	14
gap width [mm]	400	200
gap height [mm]	180	160
field gradient [T/m]	$0.39 \cdots 4.2$	$0.80 \cdots 8.0$
eff. length [m]	1.0	0.5
max. current [A]	1750	1950
max. resistive power [kW]	65.5	36.5

RF SYSTEMS

The CR rf system has to deliver a total peak accelerating voltage of 200 kV for bunch rotation over about 200 μs. 5 single rf cavities installed in one of the straight sections produce a peak voltage of 40 kV each. The system provides two different operational modes:

1. High voltage (200 kV) operation for bunch rotation with low duty cycle ($5 \cdot 10^{-4}$).

2. Moderate voltage operation for adiabatic debunching and rebunching with quasi continuous operation.

The cavities work at the first harmonic of the revolution frequency of RI beams (1.21 MHz) and antiprotons (1.41 MHz). According to a first layout of the cavities, they are filled with the amorphous magnetic alloy material VitroVac 6030F. Their Q values are 3.0 at 1.21 MHz, and 2.6 at 1.41 MHz. They are driven in push-pull mode by two Thales TH555A tubes. The total peak power per cavity is 1400 kW. Figure 3 shows a schematic sketch of the rf cavity circuit with connections to the tubes.

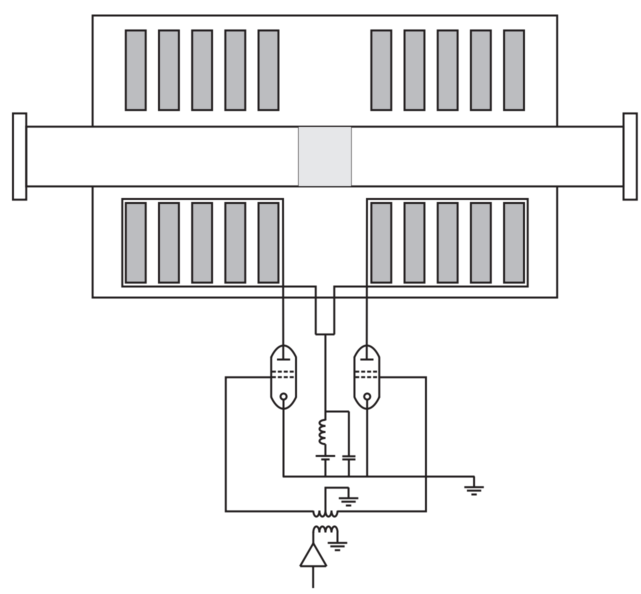

Figure 3: Layout of CR rf cavity circuit.

INJECTION AND EXTRACTION

The requirements on the injection and extraction systems depend on the different beam sizes before and after cooling. The injection kickers are located in one of the long straight sections, whereas the extraction kickers are placed in the arcs. Before extraction an orbit bump is switched on. All kickers must be bipolar.

A preliminary layout of the fast kicker magnets exists. Their main parameters are listed in Table 3. They work with loaded cables connected in parallel to lower their effective characteristic impedance. The cables are discharged by thyratron switches into the kicker magnet load.

Table 3: Fast kicker parameters

	injection	extraction
type of magnet	window frame	C-type
no. of units	3	2
no. of modules per unit	2	
deflection angle [mrad]	± 5.25	± 3.5
magnetic field [mT]	56.4	52.4
gap width [mm]	200	250
gap height [mm]	130	140
rise time [ns]	360	210
length per unit [m]	1.5	1.2
load voltage per module [kV]	70	
load current [kA]	5.83	
characteristic impedance [Ω]	6	

STOCHASTIC COOLING

The stochastic cooling systems at the CR are required to cool both antiproton and RI beams [7].

In the first stage of construction, the bandwidth of the CR stochastic cooling systems is limited to 1-2 GHz. In contrast to former designs, this will cause overall cooling times of 10 s for antiprotons and 1.5 s for RI beams. The addition of 2-4 GHz systems is reserved for the future.

There are 4 pick-up tanks (see Figure 1), namely P1-P3 at zero dispersion locations in a straight section, and the Palmer pick-up PP at large dispersion in the following arc. The kickers K1-K3 are located in the opposite straight section, again at zero dispersion. Table 4 shows the range of beam dimensions in the pick-ups and kickers immediately after bunch rotation (see Table 1). Due to the FODO lattice of the CR, the beamsize variation between entry and exit is so significant that the bars, on which the electrodes are mounted, will be slanted with respect to the beam axis.

The kickers K1-K3 are used for all kinds of beams. Antiproton cooling applies the signals from the pick-ups P1-P3. Longitudinal cooling uses the notch filter method. In the case of RI beams, to minimize undesired mixing the Palmer pick-up PP is used for cooling in all phase planes as long as the momentum spread is larger than $\pm 1 \cdot 10^{-3}$.

Table 4: Range of beam dimensions of both beam species at pick-up and kicker tanks after debunching

	antiprotons		rare isotopes	
	x [mm]	y [mm]	x [mm]	y [mm]
P1,K3	66-111	63-108	83-111	35-49
P2,K2	66-107	67-108	83-116	38-50
P3,K1	63-107	69-118	83-116	40-60
PP	-		142-158	115-133

Only at the very end of the cooling cycle the system is switched to the pick-up signals from P1-P3 in order to produce the high final phase space density.

All pick-up tanks are cryogenic leading to effective system temperatures of about 30 K. Cryogenic preamplifiers are used, as well. All tanks are equipped with plunging electrode supports.

Slotline electrodes [8], [9] are applied both as pick-up and kicker. They are simultaneously applicable at the two different velocities of RI and antiproton beams, and offer a sensitivity which is superior to many former designs. The details of their engineering design are being developed.

It is foreseen to build an array of slotline electrodes which can be tested at the ESR storage ring at GSI with beam conditions close to those at the CR. The maximum magnetic rigidity of the ESR (10 Tm) would allow for the storage of fully stripped beams with $A/Q = 2.0$ at the future CR energy of 740 MeV/u.

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REFERENCES

[1] S. Litvinov et al., this conference.

[2] P. Beller et al., this conference.

[3] M. Steck et al., this conference.

[4] A. Dolinskii, K. Beckert, P. Beller, B. Franzke, F. Nolden, M. Steck, Nucl. Inst. Meth. A 532 (2004) 483-487.

[5] A. Dolinskii, K. Beckert, P. Beller, B. Franzke, F. Nolden, M. Steck, Proc. EPAC 2004, 1177-1179.

[6] P. Beller, K. Beckert, A. Dolinskii, B. Franzke, F. Nolden, C. Peschke, M. Steck, Proc. EPAC 2004, 1174-1176.

[7] F. Nolden, K. Beckert, P. Beller, A. Dolinskii, B. Franzke, U. Jandewerth, I. Nesmiyan, C. Peschke, P. Petri, M. Steck, F. Caspers, D. Möhl, and L. Thorndahl, Proc. Cool '05, AIP Conf. Proc. **821** (2006) 177-184.

[8] C. Peschke, F. Nolden, M. Balk, Nucl. Inst. Meth. A 532 (2004) 459-464.

[9] C. Peschke, F. Nolden, and L. Thorndahl, Proc. Cool '05, AIP Conf. Proc. **821** (2006) 221-225.