COOLING STORAGE RING CR OF THE FAIR FACILITY - STATUS AND PERSPECTIVES*

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Abstract

In 2014 BINP takes full responsibility on the design and construction of the Collector Ring of the FAIR facility. Still few work-packages remain be on the supervision of GSI' team. In this paper the current status of the CR project is presented and future plans are discussed.

INTRODUCTION

The Collector Ring (CR) at FAIR [1,2] is a dedicated storage ring which will fulfill the following tasks (next column). Its layout and location of subsystems are shown in the Fig. 1, parameters are presented in the Table1.

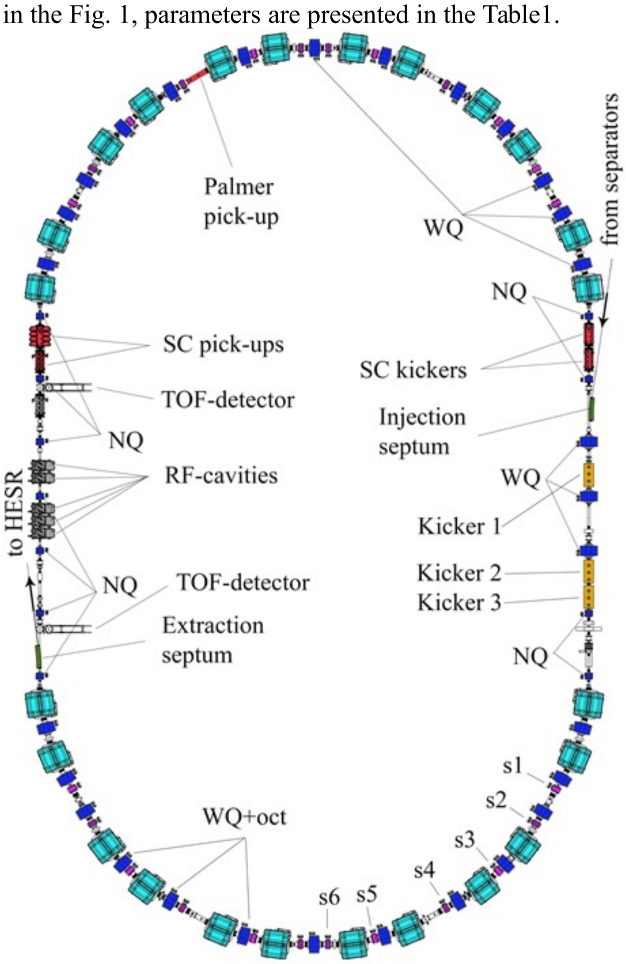

Figure 1: Layout of CR ring.

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Main tasks for Collector Ring operations:

- Stochastic cooling of antiprotons coming from the antiproton separator, to be delivered to the HESR (later to RESR) storage ring.
- Stochastic cooling of rare isotope beams (RIB) coming from the Super-FRS fragment separator, to be delivered to RESR.
- TOF measurements of masses of short-lived secondary rare isotopes in the isochronous mode.

Table 1: Main parameters of Collector Ring

Circumference	**221.45 m**		
B·ρ	13 Tm		
Mode	**p-bar**	**RIB**	**Isochronous**
Max. N	10^8	10^9	$1\text{-}10^8$
Kinetic energy	3 GeV	740 MeV/u	400-790 MeV/u
Lorentz γ	4.20	1.79	1.43 – 1.84
Transition γ_{tr}	3.85/4.84	2.71/2.95	1.43 – 1.84
Slip factor $\lvert\eta\rvert$	0.011	0.178	0
Acceptance	240	200	100
Max $\Delta p/p$	±3%	±1.5%	±(0.22–0.62)%

LATTICE

The lattice of the CR consists of two 180 degree arcs separated by two long straight sections. Because of the large acceptance of the CR, it is important to use large aperture magnets only where they are needed. In order to minimize both the production and operating costs, wide aperture quadrupole magnets with useful aperture 400mm by 180 mm are used for the injection section and in the arcs of the CR. The narrow quadrupole magnets with reduced horizontal good field region (useful aperture 180 mm by 180 mm) are installed only in the straight sections.

A list of magnetic elements includes:

- 24 dipole magnets
- 29 wide aperture quadrupoles (WQ) and 11 narrow aperture quadrupoles (NQ) will be used.
- 6 families of sextupoles (s1-s6) will be applied to control the chromaticity and the dispersion in the arcs.
- 3 families of octupole correctors embedded into wide quadrupoles (WQ+oct) are needed for corrections of mass measurement accuracy.
- Orbit correctors in dipoles and in drifts

According to the list of tasks, there were developed 2 basic optical schemes: one for antiproton beam cooling,

ISBN 978-3-95450-170-0

the second for rare ions plus 3 different variants for the isochronous operation mode. In all cases the thorough optimization of the dispersion and beam amplitude functions was made. Results are presented in Fig. 2. Another care was paid to provision of needed phase advances between pickups and kickers of the stochastic cooling system.

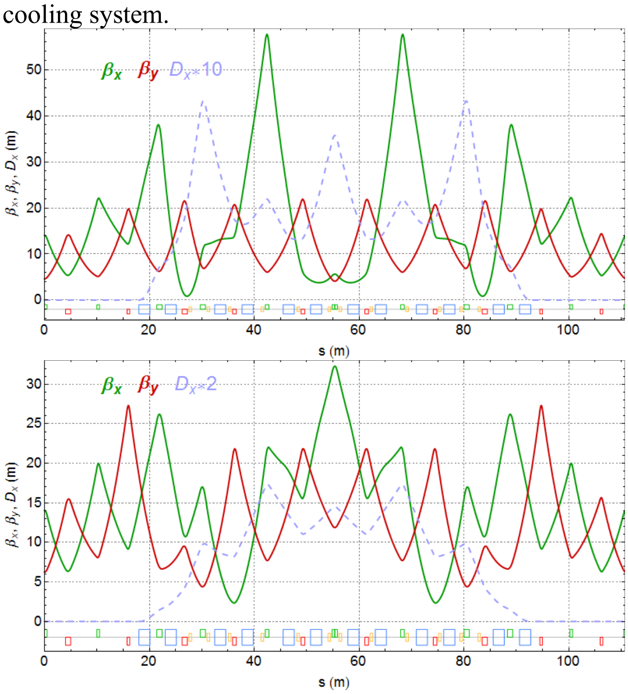

Figure 2: Lattice functions p-bar and RIB mode.

The main element of CR is a bending magnet. Its view is shown in the Fig. 3-4 and main parameters are listed below:

- Laminated, lamination thickness 1 mm
- Sector shape poles and coils
- Bending angle 15^0
- Maximum field 1.6 T
- Bending radius 8.125 m
- Pole gap 170 mm
- Useful aperture 380 by 140 mm
- Field homogeneity $\pm1\cdot10^{-4}$ (at 1.6 T)
- Design ramp rate 1 T/s
- Maximum current 1396 A

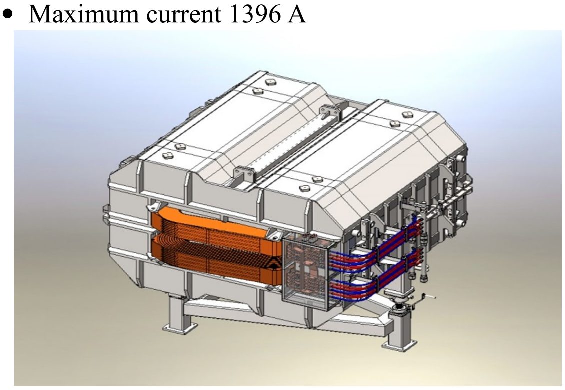

Figure 3: 3d model of the CR dipole magnet.

Main parameters of quadrupoles are listed in Table 2.

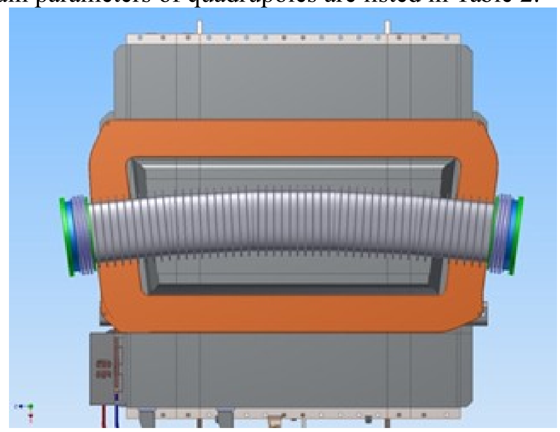

Figure 4: Half of the dipole yoke with the 2 mm thick elliptical vacuum chamber with ribs.

Table 2: The reference parameters of quadrupoles

Quadrypole type	WQ	NQ
Effective length, m	1.0	0.5
Maximum gradient, T/m	4.9	9.0
Useful aperture, mm×mm	400×180	180×180
Field homogeneity	$\pm5\cdot10^{-4}$	$\pm5\cdot10^{-4}$

NONLINEAR EFFECTS

Special feature of CR storage ring is the large 6D acceptance. The initial emittance of injected antiprotons will be as large as 240 mm·mrad in both transverse directions, while momentum spread amounts to ±3%. Thus, it is important to study carefully different chromatic and nonlinear effects.

Six sextupole magnet families are foreseen for compensation of linear chromaticity. The closed orbit distortion for the off-energy particle can be written as

$$\delta x(s) = D\cdot\delta + D_1\delta^2 .$$

The second-order dispersion function D_1 is presented in Fig. 5. Chromaticity of lattice functions was also examined. Accurate calculations made by 6D SAD code [3] for lattice functions of off-energy particles with momentum deviation of ±3% are shown in Fig. 6.

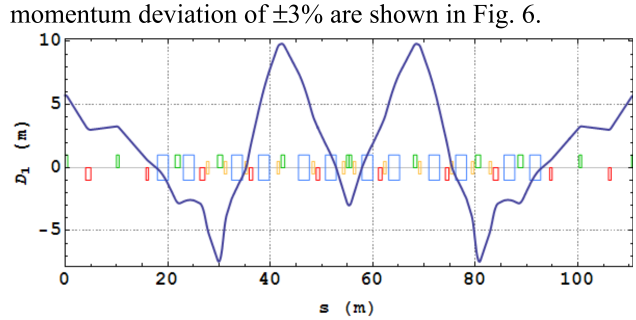

Figure 5: Second order dispersion (p-bar mode).

The beam size with mentioned above chromatic aspects taken into account are shown in Fig. 7. Chromatic

ISBN 978-3-95450-170-0

sextupoles is an essential source of nonlinear magnetic fields that can result in the instability of betatron motion for large enough oscillations amplitudes.

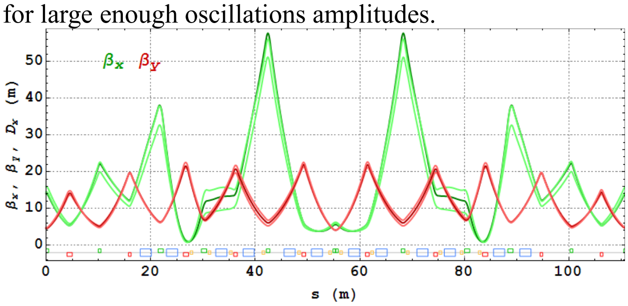

Figure 6: Lattice functions for on-enegy particle (dark) and off-energy particles (light).

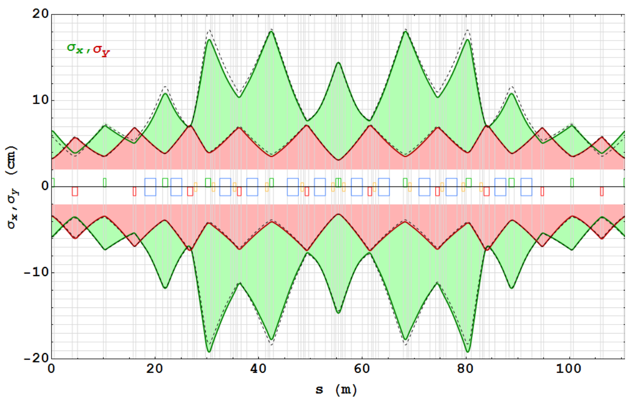

Figure 7: Beam size along one half of the ring.

The Dynamic Aperture (DA) simulated numerically by the use of PTC tracking module of the MAD-X code [4]. Particle trajectories are integrated over 1000 turns. Fringe field and the higher-order harmonics [5] have been included in the computation. Results are shown in the Fig. 8.

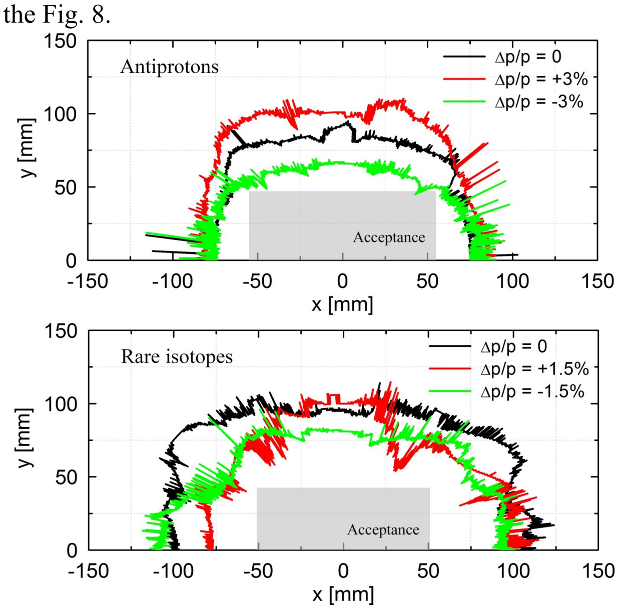

Figure 8: MAD-X dynamic aperture simulation results.

ISOCHRONOUS MODE

Precise determination of rare isotope masses requires the absolute accuracy of $dT/T=10^{-6}$ in the TOF measurements of the revolution time [6]. 3 families of quadrupoles and 3 families of octupole correctors embedded into the wide quadrupoles (WQ+oct) in the arcs (totally 12 magnets of each type) can be applied to correct the impact of field errors and fringe field of the magnets on the measurement accuracy, see Fig. 9.

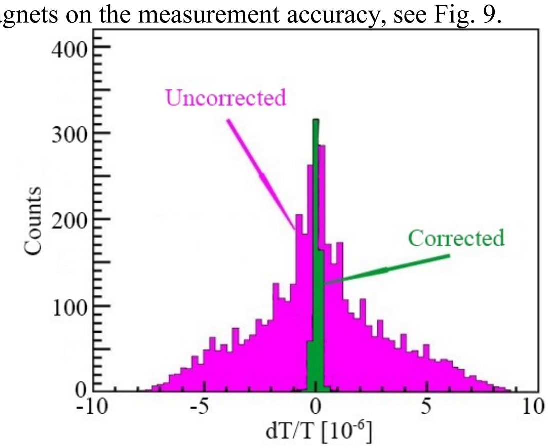

Figure 9: Effect of sextupole and octupole corrections on TOF distribution.

INJECTION-EXTRACTION

Injection system consists of 3 pulsed bipolar magnetic kickers (Kicker 1, Kicker 2 and Kicker 3) and the pulsed injection septum magnet. Full aperture kickers are needed to guarantee the large injection acceptance. Maximum kick angle of 7 mrad for each kicker is required for the injection [2]. Maximum kicker voltage is 70 kV. Maximum current is 6140 A. Rise/fall time is 318 ns. Maximum pulse length is 1.5 µs. Same kickers are used for extraction. The septum magnet design is under development.

CONCLUSION

A great variety of optical schemes were developed for different operation modes of the CR. Many linear and nonlinear dynamics studies were performed up to now. No show-stoppers were found on this way. Still, many technical problems and solutions need to be solved in nearby future.

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ISBN 978-3-95450-170-0