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STATUS OF ION-OPTICAL DESIGN OF THE COLLECTOR RING

O. Gorda, A. Dolinskii, S. Litvinov, GSI, Darmstadt, Germany
D. Berkaev, I. Koop, P. Shatunov, D. Shwartz, BINP, Novosibirsk, Russia

Abstract

In this paper the recent updates concerning the ion-optical properties of the large acceptance Collector Ring (CR) are presented. The layout of the straight sections has been modified to have more installation space for the CR components. It has been demonstrated that the ring acceptance can be optimized by the small modification of the quadrupole arrangement in the arcs. We have revised the injection and extraction optics taking into account the modified layout of the ring. Particle tracking calculations have been performed to calculate the CR dynamic aperture for the present lattice. For mass measurements in the isochronous mode, the possible correction scheme has been proposed to improve the mass resolving power. The latest results are described in this work.

INTRODUCTION

The Collector Ring [1] is a dedicated large acceptance storage ring designed for stochastic cooling of hot antiproton or rare isotope (RI) beams at FAIR [2]. It will also be operated in the isochronous mode [3] to measure masses of short-lived secondary rare isotopes. Having in mind the multi-functionality of the CR its optics has to be flexible providing the large transverse and momentum acceptance in all three optical modes. The detailed overview of the lattice design and parameters is given earlier in [4]. During the last few years the layout has been modified taking into account the requirements to the flexibility of the optics as well as the requirements given by the injection and extraction, stochastic cooling system and the need to have more installation space for the CR components. The full description of the latest version of the CR and its subsystems has been presented in the updated CR Technical Design Report [5] which was approved and released earlier this year and is to be published soon. The 1-2 GHz stochastic cooling (SC) system and its requirements to the ring optics are described in details in [6-8]. In the antiproton mode, the CR will be operated with the chosen ring slip factor $|\eta|=0.011$ guaranteeing the optimum momentum acceptance for the notch filter cooling. The stochastic cooling of rare isotopes is optimized for $|\eta|=0.178$. All pick-ups and kickers of the SC system must be located at positions with zero dispersion, except of one special pick-up based on the Palmer method. The Palmer pick-up must be located at a position with high dispersion and it will be applied at the beginning of cooling for RI beams. An important feature of the CR is the large injection acceptance which must be guaranteed for all optical modes. For the effective injection and extraction, the correct phase advance between the septa and kicker magnets is required. The modified CR lattice presented in this paper has been considered taking into account all the requirements to the ring optics including those described above.

THE COLLECTOR RING

In the modified version of the CR lattice the circumference of the ring has been increased and already fixed at 221.45 m. The dipole magnets designed by BINP, Novosibirsk will have a rectangular yoke with sector-shaped poles and coils. In comparison to the previous options, only three 1m long wide aperture quadrupoles are located in the straight sections namely in the injection area where the large aperture for the injected beam is required.

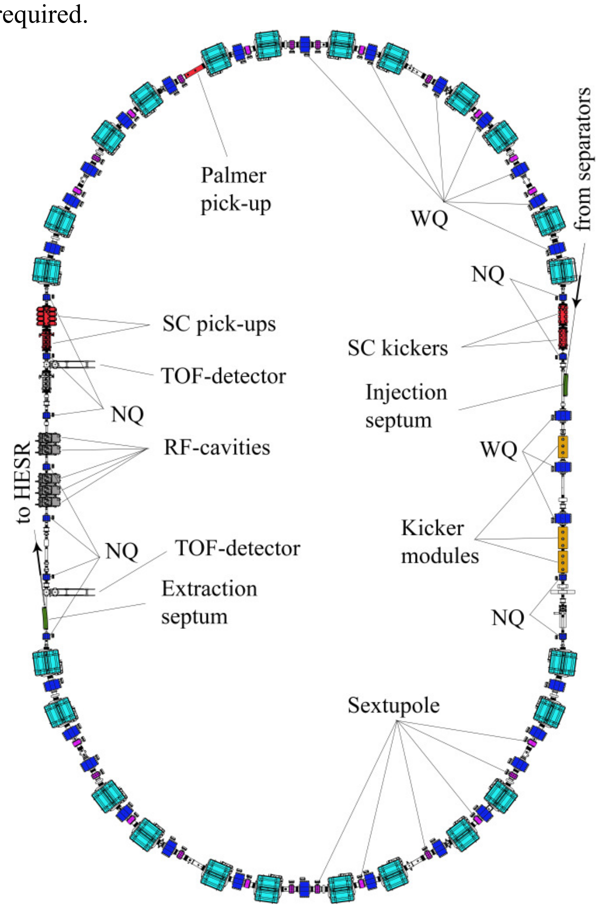

Figure 1: Layout of the CR, where WQ – wide aperture quadrupole, NQ – narrow aperture quadrupole.

All other quadrupoles in the straight sections will be of narrow aperture type with the length of 0.5 m, see Fig. 1. The length of the drift spaces where the RF-cavities will be installed has been therefore increased from 4 m to 4.5 m. The length of the adjacent drift spaces is increased to 5.25 m. In the arcs of the CR, only wide aperture quadrupoles and sextupoles will be installed in order to

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provide the momentum acceptance of ±3% for antiprotons and ±1.5% for RIs. The main ion-optical parameters of the modified CR lattice are summarized in Table 1.

Table 1: Ion-Optical Parameters of the CR

Circumference	221.45 m	
Max. rigidity	13 Tm	
	Antiprotons	**Rare isotopes**
Lorentz γ	4.20	1.79
Transition γ_{tr}	3.85 or 4.84	2.71 or 2.95
Frequency slip factor $\|\eta\|$	0.011	0.178
Acceptance mm mrad	240	200
Momentum acceptance	±3%	±1.5%

Injection and Extraction

The injection and extraction system [5] of the CR consists of 3 pulsed magnetic kickers and two pulsed septum magnets. The phase advance of about $\pi/2$ between the injection septum and the kickers is provided by their proper arrangement in the adjacent drift spaces as shown in Fig. 1. In order to guarantee the large injection acceptance, full aperture kicker magnets are required. The maximum kick angle of 7 mrad for each kicker magnet allows to get the separation of about 60 mm between the septum edge and the centre of the circulating beam at the position of the injection septum. Fig. 2 shows the beam envelopes of the injected and circulating beam.

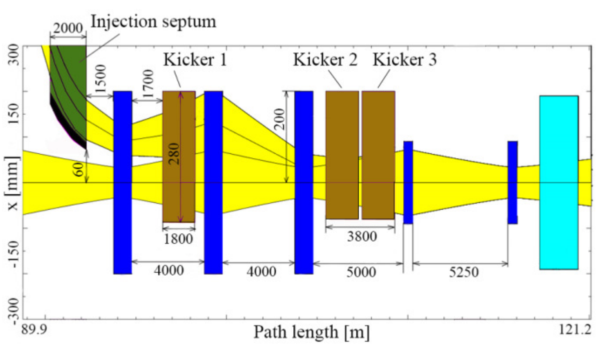

Figure 2: Beam envelopes of the injected and circulating beam propagating through the injection septum and three kicker magnets.

For the extraction of the antiproton or RI beam the extraction septum magnet and two kicker magnets (Kicker 2 and Kicker 3) located close to the arc are needed. To provide a maximum beam deviation at the position of the extraction septum the phase advance between the kicker and septum magnets has to be close to $n\cdot\pi/2$, where n is an odd integer. In the present CR optics, n=7 for antiprotons and n=5 for RIs. The maximum kick angle of 5 mrad for each kicker magnet is required.

Lattice Optimization

Flexibility of the CR optics allows to optimize ion-optical properties taking into account the requirements given by the stochastic cooling and injection/extraction system. The proposed option of the acceptance optimization for the antiproton optics implies the slight rearrangement of several wide aperture quadrupole and sextupole magnets in the arcs. The positions of the WQs quadrupoles and sextupoles located in sections S3, S4 and S5 have been interchanged as shown in Fig. 3.

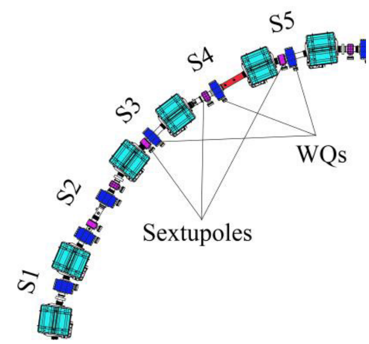

Figure 3: One half of the CR arc with the proposed rearrangement of wide aperture quadrupoles (WQs) and sextupoles in the sections S3, S4 and S5.

The effective length of the WQs quadrupoles in sections S3, S4 and S5 has been reduced from 1 m to 0.7 m aiming at getting enough space for the installation of the vertical corrector magnets. Due to the shift of the quadrupoles close to the middle of the sections the maximum dispersion D_x in the arcs can be decreased from 5.1 m to 4.3 m in the antiproton optics as shown in Fig. 4.

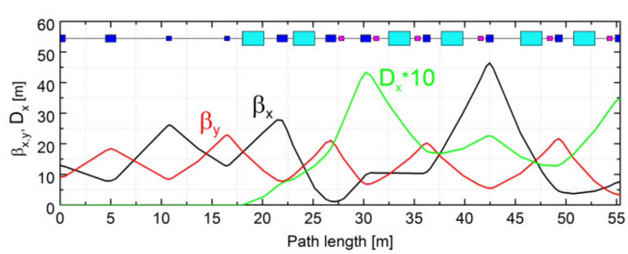

Figure 4: Dispersion and β-functions of one quarter of the CR in the antiproton optics.

This option implicates the operation of the CR above the transition in both the antiproton and RI optics since the transition energy is $\gamma_{tr} = 4.84$ in the antiproton optics and $\gamma_{tr} = 2.95$ in the RI optics. Due to the more regular distribution of quadrupoles in the arcs the vertical betatron tune Q_y in the antiproton optics can be reduced from 4.88 to 3.23 while the horizontal tune Q_x is changed from 4.31 to 4.18. In the RI optics, the optimized lattice implies the betatron tunes of Q_x/Q_y = 3.18/3.23. The dispersion and the β-functions for the RI mode are shown in Fig. 5.

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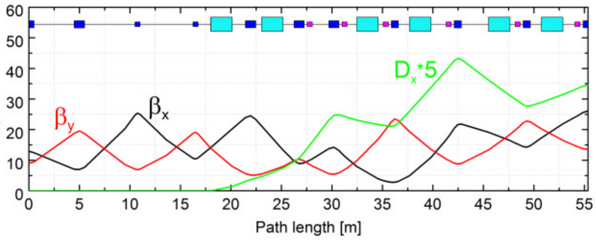

Figure 5: Dispersion and β-functions of one quarter of the CR in the rare isotope optics.

Dynamic Aperture

The large emittance and momentum spread of the injected beams requires careful controlling of the nonlinear dynamics as it may bring a part of the beam into a resonance and cause the beam losses. Large off-momentum dynamic aperture is therefore essential for all optical modes. The main nonlinear source is provided by 6 families of sextupoles (totally 24 magnets) used to control the ring chromaticity as well as the dispersion function in the straight sections close to zero. The impact of the sextupolar field, fringe field and field errors of the large aperture CR magnets is extensively described in [9]. In this paper we present the results of the dynamic aperture calculations performed for the modified lattice of the ring. The calculations have been done using the PTC tracking module of the MAD-X code [10]. Particle trajectories are integrated over 1000 turns. Higher-order field harmonics as given in [9] and the fringe field of the magnets has been included in the computation.

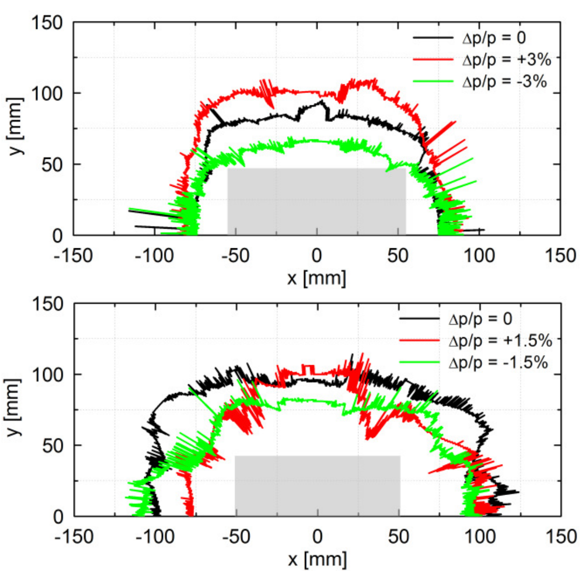

Figure 6: Dynamic aperture of the CR in the antiproton (upper) and the rare isotope (lower) optics. The betatron tunes are Q_x/Q_y = 4.18/3.23 for antiprotons and Q_x/Q_y = 3.18/3.23 for rare isotopes.

The calculated dynamic aperture is larger than the ring acceptance (shown in grey) for both optical modes as depicted in Fig. 6. In comparison to the previous lattice versions described in [4, 9] the off-momentum dynamic aperture in the antiproton optics has been significantly improved due to the lattice optimization.

THE ISOCHRONOUS OPTICS

Precise determination of rare isotope masses in the isochronous mode of the CR requires the absolute accuracy of $dT/T=10^{-6}$ in the measurements of the revolution time [3]. To compensate the impact of the field errors and fringe field of the magnets on the measurement accuracy a special correction scheme is needed. The proposed scheme for the present CR lattice implies the use of 3 families of sextupoles and 3 families of octupole correctors embedded in the wide aperture quadrupole magnets in the arcs, i.e. totally 12 magnets of each type are applied. As an example we demonstrate how the resolution of the revolution time determination for the beam with the emittance of 100 mm mrad and the momentum spread of ±0.2% can be improved. According to the calculations performed for the isochronous optics with γ_{tr}=1.43, under such conditions the proper correction scheme allows to get the resolution of about 10^{-6} as shown in Fig. 7.

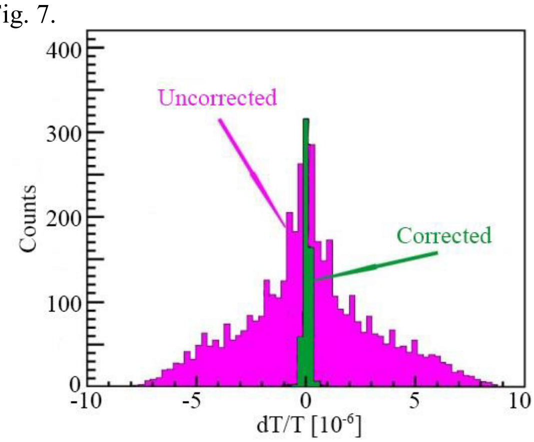

Figure 7: The calculated revolution time signal after 100 turns in the isochronous optics of the CR.

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