COLLECTOR RING PROJECT AT FAIR: PRESENT STATUS*

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Abstract

In November 2013, the FAIR management delegated the responsibility for the technical design, construction, installation, and commissioning of the whole Collector Ring and its components from GSI to Budker Institute of Nuclear Physics (BINP). Since that time a lot of modifications of the original design were made aiming to improve the beam parameters and the machine performance. This work shows the present status of the development.

INTRODUCTION

Collector Ring (CR) is one of the key installations of the FAIR project (Darmstadt, Germany). It is dedicated for stochastic cooling (SC) of incoming beams of antiprotons and rare ions. The cycle of the CR operation consists of injection, RF stretching, SC and finally extraction towards the HESR. Additionally there is a mode of operation for experiments with precise mass measurements of the particles in the ring. Main parameters of the storage ring for three main modes of operation are shown in Table 1. The sketch of the ring is presented in the Figure 1.

Table 1: The CR Main Parameters

	Antiprotons	Ions
Perimeter, Π	221.451 m	
Rigidity, Bρ	13 T·m	
Number of particles, N	10^8	10^9
Kinetic energy, K	3 GeV	740 MeV/u
Velocity, v	0.971c	0.830c
Relativistic factor , γ	4.20	1.79
Betatron tunes, ν_x, ν_y	4.39, 3.42	3.40, 3.44
Revolution frequency, ω_0	1.35 MHz	1.16 MHz

The work of BINP was based on the final version of the Technical Design Report (TDR) for the CR that was released by the GSI team in February 2014 [1]. Since that time a lot of modifications of the original design were made aiming to improve the beam parameters and the machine performance. All these changes were reported to the Machine Advisory Committee (MAC) in 2014 and 2015 and following its recommendations were published as a TDR Annex in 2016 [2]. These two Annexes to the TDR summarize all changes to the CR design made since February 2014. Here the part of the work done in BINP is presented.

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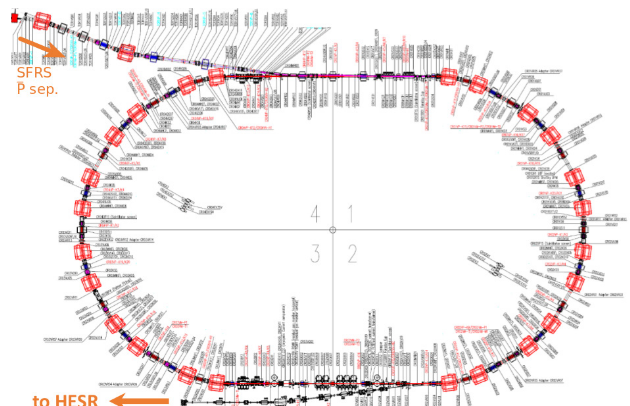

Figure 1: The Collector Ring overview.

LATTICE

The huge work was done to adopt the projects lattice to various demands coming from RF-system, SC-system, Injection/Extraction system and HESR team, taking into account all modes of operation. The apertures and lengths of magnets as well as conceptual design of all the correctors and beam diagnostic components were changed. Some magnetic elements were rearranged. Totally new concept for vacuum system was proposed.

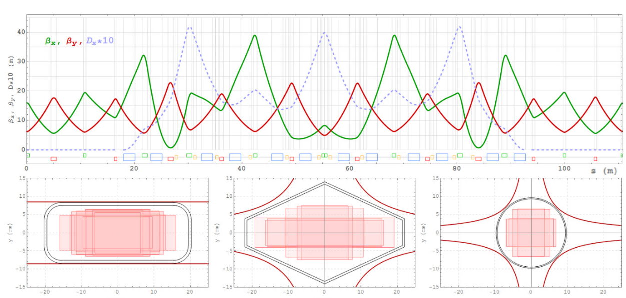

Figure 2: The lattice functions of the CR for the anitproton mode of operation and matching of the beam sizes to the aperture in the elements: the bending magnet, wide quadrupole and narrow quarupole (from left to right).

All these numerous changes were supported by adaptation of linear lattice with control of self-consistence of beam sizes, betatron phase advances between key azimuths, magnets apertures etc. Finally, in the end of 2015 the acceptable solution of overall CR conceptual design was found and the lattice (for all three operation modes) was frozen (see Fig. 2).

Since the momentum spread is very large in injected beam the natural betatron tunes chromaticity must be

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compensated to fit beam footprint between resonances. Also it is important to control second-order chromatic effects (second-order dispersion function, lattice function chromaticity) to avoid strong chromatic variation of beam sizes where the aperture is limited, and variation of betatron phase advances between SC components.

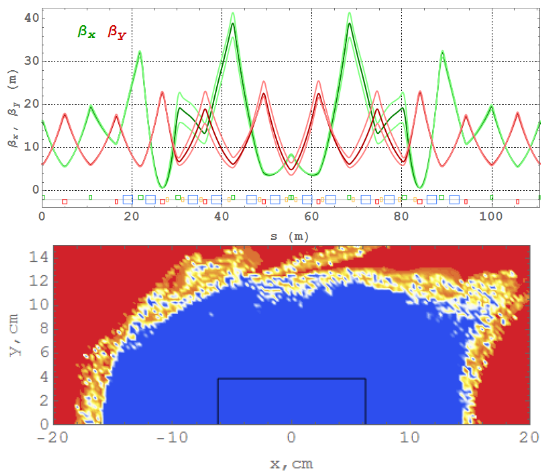

Figure 3: The chromatic effects of the lattice functions in one half of the ring (up) and the dynamic aperture estimation for the CR in the antiproton mode (bottom). The black rectangle in the middle matches to the physical aperture of the ring.

There was found a scheme to suppress these effects with use of 6 families of sextupole magnets [3]. However sextupole magnets are the main source of nonlinear fields. The dynamic aperture was checked for this scheme taking into account the nonlinearities of main magnetic elements and random deviations in strength and rotation of the quads and sextupoles (see Fig. 3).

MAGNETIC ELEMENTS

Extremely high acceptance of the ring (240 mm*mrad) leads to large apertures of all magnetic elements including the septum magnets. Meanwhile desired parameters of the magnetic field and magnetic field quality are comparatively strict. All magnets are iron dominated with laminated yoke. The standard production technology will be used while the quality is achieved by the yoke geometry. Here the short review of all the magnetic elements is given.

Bending Magnet

The CR will use normal conducting dipole magnets (see Fig. 4). There will be 24 H-type sector magnets with a deflection angle of 15° with a maximum field value of 1.6 T. The usable magnet gap will be 140 mm, while the horizontal good field region amounts to 380 mm. The integrated 5,37 смover the length of the magnet field quality as a function of radius is $\Delta B{\cdot}l/B{\cdot}l = \pm 1{\times}10^{-4}$ as required from the beam dynamics simulations. This challenging field quality is necessary mainly for precise experiments with ion beam in ISO regime. Below 1.6 T the value $\Delta B{\cdot}l/B{\cdot}l$ can be higher with a linear approximation up to $\pm 2.5{\times}10^{-4}$ at the field level of 0.8 T.

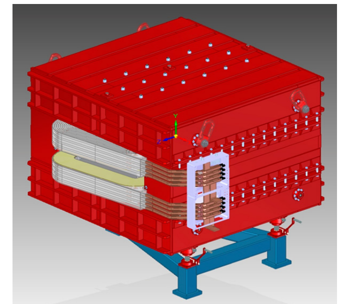

Figure 4: The 3D model of the designed dipole.

The present layout proposes a coil with total current of 88×1420 A. The required DC power for this magnet amounts to 126 kW. To change the polarity between maximum field levels within a minute the ramp rate of 0.054 T/s is required presently for the dipole power converter.

Quadrupole Magnets

Because of the large acceptance of the CR, it is important to use large aperture magnets only where they are needed.

Table 2: Main Parameters of the CR Quarupole Magnets

	Wide	Short Wide	Extended Wide	Narrow
Number of magnets	14	12	3	11
Maximum gradient [T/m]	4.7	4.7	3.5	6.2
Inscribed radius [mm]	160	160	185	100
Effective length [m]	1.0	0.7	1.0	0.5
Integrated gradient [T]	4.7	3.29	3.5	3.1
Field homo-geneity $\Delta B/B$	$\pm 5{\times}10^{-4}$	$\pm 5{\times}10^{-4}$	$\pm 1{\times}10^{-3}$	$\pm 5{\times}10^{-4}$
Coil current [A]	1470	1480	1470	1210

The extremely wide aperture quadrupole magnets with useful aperture 450 mm × 180 mm are used for the injection section (inscribed to poles radius 185 mm) (see Table 2). In the arcs two other types of wide aperture quadrupoles with pole radius 160 mm will be installed. One group of 14 quadrupoles has the useful aperture 400 mm × 180 mm and the effective magnetic length 1 m. The other group of 12 quadrupoles has the same aperture but shorter effective length equal to 0.7 m. The narrow quadrupole magnets (useful aperture 180 mm × 180 mm, pole radius 100 mm) are installed only in the straight sections.

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Sextupole Magnets

24 sextupole magnets are used in CR. 3D modelling (see Fig. 5) was done to achieve the desired parameters: the maximum strength of 10 T/m^2, the effective length of 500 mm, the inscribed radius of 201 mm, the useful aperture of 430 × 180 mm^2, the field uniformity of $\pm 5\times 10^{-3}$. Coils have 22 turns for each pole with the maximum current of 500 A.

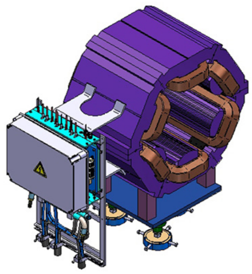

Figure 5: The 3D model of the sextupole magnet.

Dipole Correctors

Three types of steering magnets for orbit correction are proposed in the CR: additional separately powered coils embedded into dipoles; wide-aperture vertical; narrow-aperture combined-functions X/Y steering magnets.

The embedded correctors should provide angle of ±3 mrad with use of 270 turns coils with maximum current of 5.5A. The vertical correctors are of a frame type and envelope the beam position monitors. With maximum current density of 1.7 A/mm^2 the maximum field is 0.045T over the effective length of 740mm.

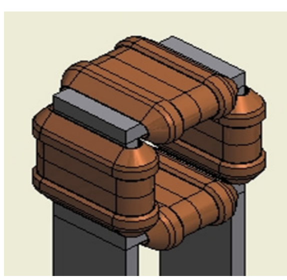

Figure 6: The 3D model of the combined steering magnet.

Combined Steering Magnets (see Fig. 6) with narrow aperture are window-frame magnets with two pairs of separately powered coils. The maximum field of 0.067 T over the effective length of 300 mm is achieved with the current density of 1.9 A/mm^2 and gives the maximum angle of ±1.5 mrad.

Octupole Correctors

Octupole correction coils will be installed into 12 wide quadrupoles of the CR arcs (see Fig. 7) to increase the parameters of the experiment in the isochronous mode. The maximum achievable octupole gradient is 13 T/m^3 with 268 turns of the coil and the current of 6 A.

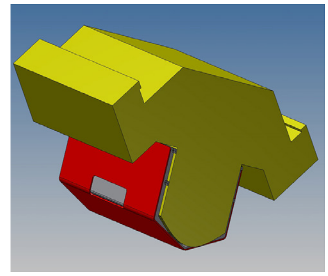

Figure 7: 3D model of the one quarter of the quad yoke with octupole coils.

Injection Septum Magnet

Three pulsed magnets (see Fig. 8) form the Injection Septum Magnet (IJS) and bend the beam for 124 mrad. C-type laminated yoke is used [4]. Magnetic field in the gap is formed with two coils – primary multiturn coil connected to the power source and secondary one-turn coil connected to the knife. The length of the pulse is 3ms. Maximum magnetic field of 0.6T is reached with the current of 5kA. The ceramic vacuum tube is used to reduce the heat losses of eddy currents.

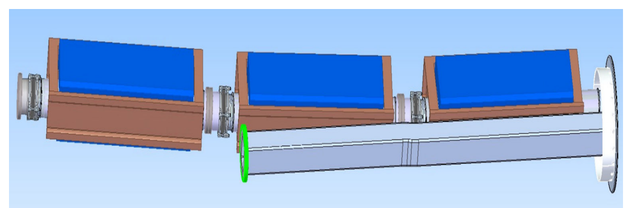

Figure 8: The magnets of ISM with the vacuum chamber.

Injection-Extraction Kicker Magnets

There are 6 kicker magnets (KM) grouped in two vacuum tanks (see Fig. 9) [5]. Same KM are used for both injection and extraction. The length of the pulse is variable from 150 to 1500 ns. The pulse of 70kV produces integrated magnetic field of 1944 mT×m that allows the kick of 15mrad in the beam. Ferrite yoke forms the magnetic flux.

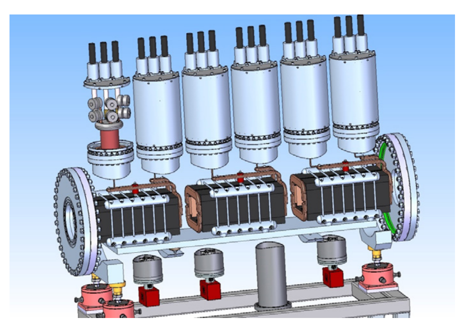

Figure 9: The set of the 3 KM in the vacuum tank.

PRODUCTION PLANS

Production plans for the elements of the ring are mainly dictated by the production of the bending magnets. According to the design 65 months are needed. It matches to the schedule of the FAIR installation procedure. All other elements fit into these dates.

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REFERENCES

[1] A. Dolinksy et al. “Technical Design Report of the CR, v.15”, 2014.
[2] V. Anashin et al., “CR TDR Annex-1”, 2016.
[3] D. Shwartz et al., “Chromatic and Nonlinear Dynamics of Antiprotons Injected to Collector Ring at Fair”, WEPSB017, these proceedings.
[4] P. Yu. Shatunov et al., “The Injection Septum Magnet for the Collector Ring (FAIR)”, Proc. IPAC’16, p.1145.
[5] A. Kasaev et al., “The Kicker System for the Collector Ring Project (FAIR)”, THPSC016, these proceedings.

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