# THE CR-RESR STORAGE RING COMPLEX OF THE FAIR PROJECT*

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*Abstract*

In the frame of the FAIR project [1] the CR-RESR storage ring complex has been designed for efficient cooling, accumulation and deceleration of antiproton and rare isotopes beams. The complex consists of the Collector Ring (CR) and the accumulator / decelerator ring RESR. The large acceptance CR will be operated in three different ion optical modes, two of them providing fast pre-cooling of either antiprotons (pbar) or rare isotope beams (RIB). The RESR will be used as antiproton accumulator by means of stochastic cooling and as a decelerator of rare isotopes.

During the last year the structures of the CR and RESR storage rings have been modified in order to improve their ion-optical characteristics with respect to efficient stochastic cooling and injection-extraction properties. The lattice modifications and their ion optical properties are described in this contribution. The results of dynamic aperture calculations for both rings are discussed.

## INTRODUCTION

The CR-RESR is a multi-purpose storage ring complex consisting of two storage rings (CR and RESR) as shown in Fig.1. Lattice considerations for both storage rings have been described in detail in Ref.[2]. The design performance of these rings was gradually improved during the last year. The essential progress is due to a complete redesign of the RESR lattice as well as to an improvement of the injection / extraction efficiency in the CR by some changes inside the long straight sections. In Table 1 the modified parameters of the CR-RESR complex are given.

Table 1: Modified parameters of the CR-RESR complex.

| **Parameters** | **CR** | **RESR** |
|---|---|---|
| Circumference, C, m | 215.9 | 239.9 |
| Number of quadrupoles | 40 | 34 |
| Transition energy, $\gamma_{tr,}$ pbar/RIB | 3.7 / 2.8 | 3.3-6.4 |
| Tune $Q_x/Q_y$ , pbar | 4.26 / 4.84 | 3.12 / 4.1 |
| RIB | 3.21 / 3.71 | |

## THE COLLECTOR RING (CR)

In comparison with a version of the CR given in Ref.[2] the layout of the long drift spaces has been modified. The distances between quadrupole magnets have been increased from 3 to 5 m. Since the ring circumference had to be kept constant, the drift increase is possible due to the removing of

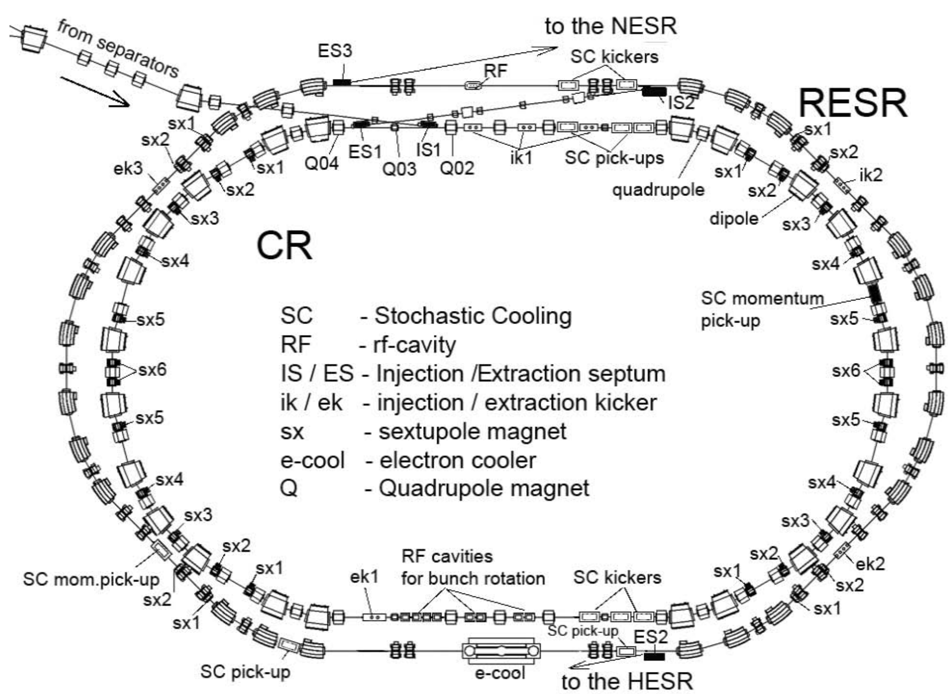


Figure 1: Layout of the CR – RESR rings.

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2 narrow quadrupole magnets from each side of the long straight sections. The remaining narrow quadrupoles were replaced by wide aperture quadrupoles. The total number of quadrupoles in the ring was reduced from 44 to 40. Figure 1 shows the present layout of the CR. As in the previous layout of the CR a stochastic cooling system and RF cavities for bunch rotation are placed in the long straight sections. Two arcs of the CR remained unchanged. The peculiarity of these arcs is that they are optimized for the achievement of efficient stochastic cooling.

### *Injection and extraction*

The key difficulty in the CR is the problem of injection and extraction into or out of the ring. The concept of an injection or extraction system is based on full-aperture fast kickers. As well as for the previous version of the CR, three full aperture kicker magnets (ik1 in Fig.1) are going to be installed, each of them having a kick angle of 6 mrad. The long drift space between quadrupoles (Q04, Q03, Q02) enables the use of only one septum for injection (IS1) and one for extraction (ES1) as shown in Figs.1,2 instead of four septa as it was planned for the previous version of the CR [2,5]

For the realization of the beam extraction from the new CR lattice only one full aperture kicker magnet is needed instead of three as planned before. This kicker will be arranged on the long drift space opposite to the extraction region (ek1 in Fig.1).

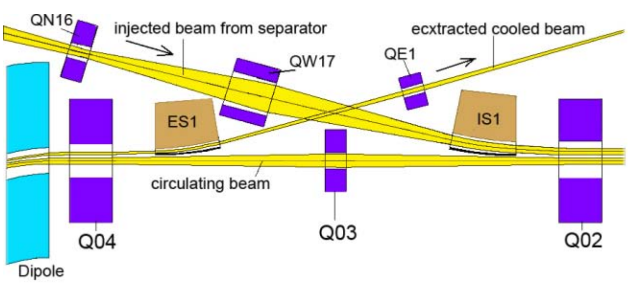


Figure 2. The injection and extraction layout of the CR. IS1 – injection septum, ES1 – extraction septum, Q – quadrupole magnet.

### *Dynamic aperture*

For the modified CR dynamic aperture calculations have been performed with different kind of magnet field imperfections. In Ref.[3] the interference effect between wide aperture CR magnets is calculated and its influence on the dynamic aperture characteristics is studied.

The special characteristics of the CR are related to large beam emittances (up to 240$\pi$ mm·mrad) and large apertures. Therefore one has to consider the non-linear effects which are associated with the motion of particles at large amplitudes. The dynamic aperture has been studied by computing the tune as a function of the betatron oscillation amplitude. A frequency map analysis by Laskar's method [4] was performed in order to identify the dangerous resonances.

For the antiproton optics, the working point is defined by the tunes $Q_x$=4.252, $Q_y$=4.845. The calculated dynamic aperture for the antiproton optics with on-momentum particles is shown in Fig.3. It is almost symmetric and larger than the ring acceptance, which is ±7 cm in the horizontal plane and ±1.8 cm in the vertical plane. The tune spread with amplitude is plotted in Fig. 4 for the whole dynamic aperture shown in Fig.3. The tune spread within the ring acceptance is much smaller (there is a small triangular region indicated by an arrow in Fig. 4). One can see only one difference resonance of 6$^{th}$ order ($Q_x$-5$Q_y$=20) which perturbs more or less the dynamic aperture. In order to see the real strength of this resonance and at which amplitude it acts, one has to use a diffusion rate of the tune variation [4]. In Figs.3, 4 this rate is depicted by a colour scale from blue for very stable orbits to red for very chaotic orbits.

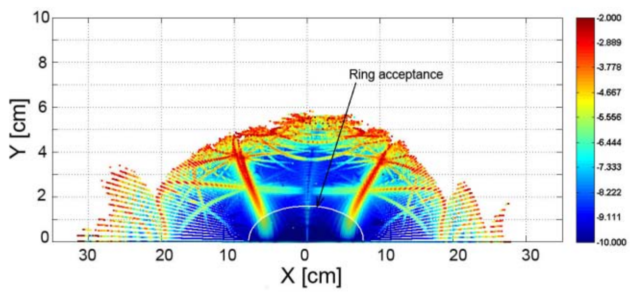


Figure 3: The dynamic aperture of the CR in the antiproton mode. Δp/p=0. Number of turns is 2000.

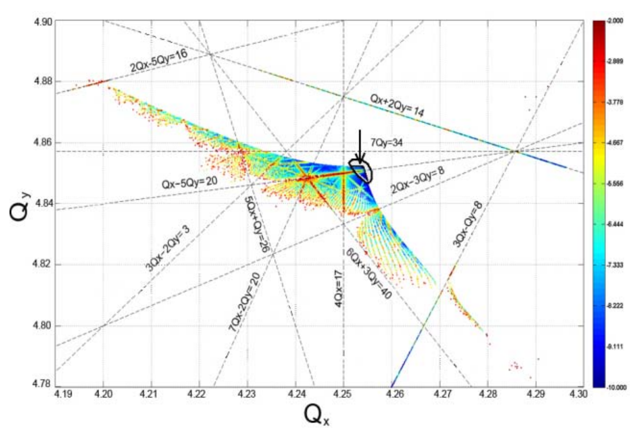


Figure 4: The frequency map for the corresponding dynamic aperture shown in Fig.3. The arrow shows the working point and the area within which the frequency spread is related to the ring acceptance.

## THE RESR

### *Lattice design*

The new layout of the RESR compared to that given in Ref.[5] has been calculated with emphasis on a high stochastic accumulation rate and the improvement of injection and extraction. The main parameters and ring characteristics are presented in Ref.[2]. It should be noted that the current lattice has a large flexibility with respect to the transition energy in the range 3.3 to 6.4 while the betatron tunes remain unchanged. This supports the accumulation of high intensity stacks of up to $10^{11}$ antiprotons. The Twiss and horizontal dispersion functions are shown in Fig.5. At the position of the momentum cooling pick-ups the dispersion is about 13 m and while the vertical beta function is below 2 m. This lattice is also suitable for fast deceleration of rare isotopes. The optical mode of the RESR can remain unchanged for both deceleration of RIBs from 740 MeV/u and for deceleration of antiprotons from 3 GeV. The new RESR lattice is much more suitable for the realization of beam injection and extraction. Instead of the three different kicker magnets with relatively strong kick angles planned for the previous version of the RESR [5], one needs three identical kickers (ik2, ek2, ek3), where the kick angle is reduced by a factor of about 2.

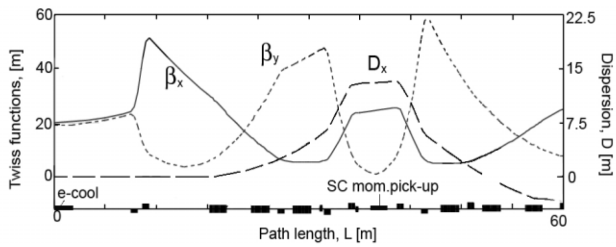


Figure.5: Twiss and dispersion functions of the RESR in one fourth of the ring circumference.

## *Dynamic Aperture*

It is important to study the sensitivity of the accumulation orbit in the ring with $\Delta p/p$=+1% to the nonlinear effects, which arise from field imperfections in the wide aperture magnets. For the dipole magnets the errors have been simulated by the OPERA code and for the quadrupole and sextupole magnets the multipole field correspond to measured values of the existing ESR magnets.

Using the PTC code the non-linear effects in the RESR were studied by computing the dynamic aperture and the tune as a function of the betatron oscillation amplitude, as it was done for the CR.

For the accumulation orbit of the RESR the betatron tunes are $Q_x$=3.20, $Q_y$=4.07. The calculated dynamic aperture and the corresponding frequency map are shown in Figs.6, 7. Within the ring acceptance several dangerous resonances ($5Q_x$=16, $Q_x$-$3Q_y$=9, $3Q_x$+$6Q_y$=34, $5Q_x$+$Q_y$= 20, $5Q_x$-$Q_y$=12) are excited and they can lead not only to instability but also to some beam loss. The most dangerous resonances are 5th order and a sum resonance of 6th order. According to the diffusion coefficient these resonances have a strong influence on amplitude growth. Hence these resonances can limit the ring acceptance and lead to beam loss. Therefore the working point of the RESR requires further optimisation and possibly correction schemes to compensate dangerous resonances.

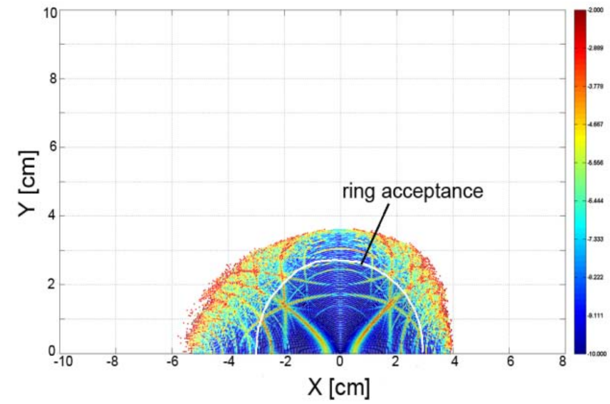


Figure 6: The dynamic aperture of the RESR for the accumulation orbit with $\Delta p/p$=1%. Number of turns is 2000.

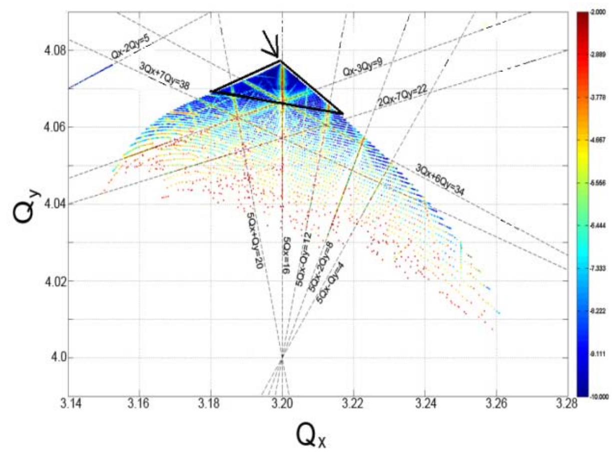


Figure 7: The frequency map for the corresponding dynamic aperture shown in Fig.6. The arrow shows the working point and the triangle area within which the frequency spread is related to the ring acceptance.

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