ORBIT CORRECTION SYSTEM AT THE COLLECTOR RING

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Abstract

The CR is a dedicated ring for cooling of hot beams coming either from the antiproton separator or Super-FRS [1]. It is anticipated that the understanding and control of the beam orbits will be important for achieving low beam losses. We describe our plans for measuring and correcting the Closed Orbit Distortion (COD) of the CR. The COD of the CR, which is distorted due to magnet misalignments, can reduce the ring acceptance by factor of 2, if a special correction system is not applied. The system, which is developed for the CR should be periodically or manually invoked to correct the global closed orbit and used to adjust the orbit position at some point using local bump. The Beam Position Monitor (BPM) and corrector magnet, which are planned to be used at the CR, are described in this paper. The numerical calculations based on the Singular Value Decomposition (SVD) algorithm have been performed in order to define possible COD without and with applying of a planned correction system. The SVD method is used to obtain the corrector strength.

INTRODUCTION

The Collector Ring (CR) [2,3], which is planned to be built in the frame of the FAIR project [4], has the multipurpose operation. Three optics are foreseen to provide fast beam cooling and mass measurements in this ring. The large ring acceptance must be guarantied at injection in all ring optics. This requires that the orbit of the particle trajectories must be as smooth as possible. The flexible orbit correction system is designed to have possibility to correct COD in all operation modes. Systematic studies of the Closed Orbit Distortion (COD) for all CR optics have been performed to define requirements for the corrector magnets. In this paper some elements of the CR correction system are presented. Because of a lack of space in ring arcs it is considered that the vertical corrector magnet can be combined with a sextupole magnet and a Beam Position Monitor (BPM) is embedded in wide quadrupole magnet. The strength of each vertical corrector in the sextupole can be varied independently from the main sextupole magnetic field. The multipole components have been calculated numerically and its influence on the beam loss has been studied.

SYSTEM DESCRIPTION

The COD correction system, which is planned for the CR, consists of four parts: 3 types of corrector magnets, corrector power supplies, a control system, and the BPM system embedded in the quadrupole magnets. The correction can be performed off-line at a very low speed, because there are difficulties for the control system to read data from BPM system and low ramping speed of corrector magnets

There are 36 correctors along the storage ring, 18 of them are used for horizontal correction and others for vertical. The software should be periodically or manually invoked to correct the global closed orbit. Also, one needs to change the orbit locally and not affecting the orbit at other site, for example, at positions of stochastic cooling pick-up and kicker tanks. This system can also be used to adjust the orbit position at some point using local bump. The software for calculation of the COD is developed. In these developments the SVD method is used to obtain the corrector strengths. The response matrix can be measured by varying the strength of the horizontal and vertical corrector magnets or constructed from calculated optics.

Beam Position Monitor (BPM)

Closed orbits have to be measured over the whole range of the very large momentum acceptance (6%) and at beam intensities as low as 5 x 10^7 particles. The CR closed orbit observation system therefore has several unusual features: large dimensions of the BPM pick-up electrodes for operation with 40 cm horizontal beam width; vacuum chamber with pick-up electrodes is located inside quadrupoles and has to be compatible with an UHV of 10^{-9} Torr; high input impedance head amplifiers mounted directly on the vacuum chamber feedthroughs.

With betatron tune values around 4.5 and the need for at least 4 points of measurement per betatron wavelength as an adequate basis for closed orbit corrections, the BPMs will be placed in every 12-14 m. The 18 stations are planned to be located in the "wide" quadrupole magnets.

At the present stage the BPM electrodes are considered to be based on the spiral shape geometry as shown in Fig.1. The disadvantage of such geometry is a strong coupling between the orthogonal electrodes.

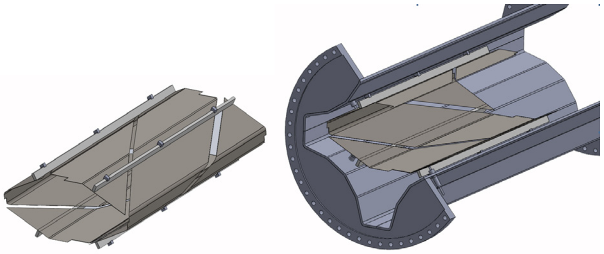

Figure 1: Schematic drawing of the spiral-shape BPM electrodes (left) and its location inside the wide quadrupole vacuum chamber (right).

Therefore, the correlation between the electrode voltages and beam positions is not straightforward as, for example, in “shoe-box” type BPM. Thus, a special algorithm will be implemented on the DAQ stage in order to obtain the beam positions. The position measurements with an accuracy better 5 mm for first turn diagnostics and an accuracy better 1 mm for the closed orbit measurement are specified. The BPM will provide orbit position measurements at 100 Hz data rate with a resolution better than 1 mm.

The BPM electrodes (Fig.1) will be rigidly embedded in the vacuum chamber. The vacuum chamber however does not touch the magnet poles, thus the magnets will keep their positions relative to the reference point.

Vertical Correctors in Sextupole Magnet

The CR layout has a limited space in the arcs to install vertical and horizontal corrector dipole magnets for using of closed orbit correction. It was decided that vertical correctors in the arcs should be combined with a sextupole magnet. 24 sextupole magnets are used to correct the chromaticity, from which 12 will be combined with vertical corrector magnets. The design of the wide sextupole magnet with a vertical corrector is developed [5]. The required (h/v) aperture of the sextupole magnet is 400x180 mm to guaranty the ring acceptance of 240 mm mrad in both planes. The field profile calculation has been performed using 2D and 3D OPERA code. The horizontal dipole field is produced by additional windings (1,2) near poles as shown in Fig.2. All these four coils together will not create any sextupole component because of the geometrical factor for the sextupole.

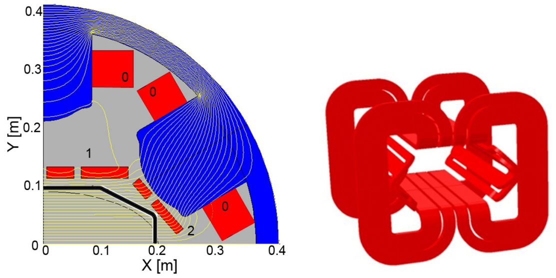

Figure 2: The sextupole magnet (left) with the embedded dipole coil (right) for vertical correction.

According to the requirements for chromaticity correction the sextupole gradient must be 12 T/m2 over the effective length of 0.6 m. The yoke length of sextupole is 0.5 m. For this magnets it was found out that one needs to generate a horizontal dipole field 0.07 T in order to perform the kick angle of 3 mrad for particles with a rigidity of BR=13 Tm. The strength of the corrector magnets is smaller than that of the main sextupole magnet and can be varied independently. 3D calculations of the higher order multipole ratios at the elliptical curvature show that required integral field error of less then 1% can be reached over the good field region of 400x180 mm (Fig.3).

In Table 1 the calculated field harmonics in cases when the sextupole magnet is excited by the main coil (Sex) and the additional windings (Sex+dip). It can be seen that incorporation of additional windings in the bore of the sextupole breaks the sextupole symmetry and introduces further unwanted multipoles including the desired one.

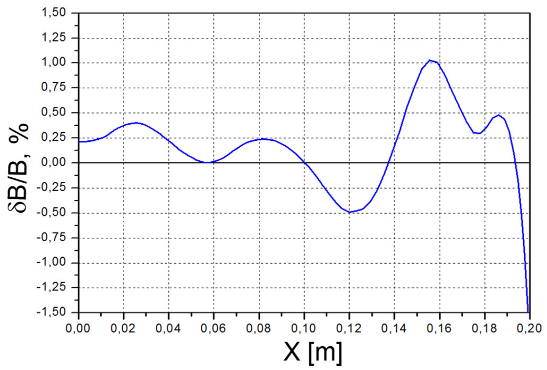

Figure 3: Flux density integrals along the border of elliptical good field area

Table 1: The normalized field harmonics b_n/b_2 in units 10^{-2} calculated at r = 200 mm. “Sex” – means excitation of only the main sextupole coil; “Sex+dip” – both the sextupole and additional coils are excited.

n	2	6	8	11	14	20
Sex	100	-	-007	-	-021	-0.013
Sex+dip	100	-0.4	-	1.23	-0.75	-

SOFTWARE DEVELOPMENT USING SVD ALGORITHM

To calculate the COD and its correction a special computer CODTRACK code has been developed. By using this code the corrector strengths are identified based on the following algorithm. Consider there are *m* BPMs and *n* corrector magnets available to the beam steering algorithm. Changes in corrector strength □□ (vector of length *n*) will reduce the orbit error □*x* (the vector of length *m*) at BPM. One gets two vectors, which are linearly related through so called a response matrix R_{ij}

$$\Delta x_i = \sum_{j=1}^{n} R_{ij}\theta_j \,, \tag{1}$$

where R_{ij} is written by

$$R_{ij} = \frac{\sqrt{\beta_i \beta_j}}{2\sin(\pi Q)} \cos\left(\left|\mu_i - \mu_j - \pi Q\right|\right), \tag{2}$$

here the β_i and β_j are the betatron amplitudes at *i-th* BPM and *j-th* corrector, Q is betatron tune and μ is a phase advance. The R_{ij} can be experimentally determined by changing the strength of *j-th* corrector by unit excitation and measuring the resulting beam motion at all BPMs while rest of correctors are set to 0. Using the matrix form of Eq.1 the corrector settings can be computed by

$$\Delta\theta = R^{-1}\Delta x \,. \tag{3}$$

The inverse matrix R^{-1} must be calculated. In the CODTRACK code the Singular Value Decomposition (SVD) method [6] is applied, where the matrix R is represented through the 3 matrixes *U, W* and *V* by

$$R_m = U \cdot W \cdot V^T \,. \tag{4}$$

U is (m x m) unitary matrix, W is (m x n) diagonal matrix that contains all the singular values, and V is an (n x n)

unitary matrix. The inverse of the matrix R_{ij} is calculated by

$$R_m^{-1} = V \cdot W^{-1} \cdot U^T , \qquad (5)$$

where W^{1} can be constructed by inverting the singular values and then taking a transpose of the matrix. Here, it is a diagonal matrix of dimension (n x m) and the elements are given by

$$W^{-1} = q_{\min(i,j)} \delta_{ij} , \qquad (6)$$

Where q_n is $1/w_n$ and zero if $w_n \le \varepsilon w_{max.}$, n is in the range of [1, min(m,n)], ε is the singularity rejection parameter in the range of [0,1]. This parameter is determined primarily by the orbit correction needs and the corrector strength limits.

CODTRACK Calculations for the CR

The CODTRACK code gives possibility to calculate a numerous quantity of CODs and afterword to carry out the analysis of the uncorrected and corrected CODs as well as the strength of corrector magnets. In the CR to have a good statistics the $2x10^4$ different sets for the magnet and BPM misalignments have been generated. Then the CODs are calculated and analyzed before and after correction applying. In calculations the random misalignments, roll and longitudinal placements of the dipoles, quadrupoles and Beam Position Monitor (BPM) in both horizontal and vertical planes have been introduced. The worst case was considered, when the sigma of the magnet misalignments is 0.5 mm and magnets have a roll with a sigma of 0.5 mrad and BPMs have the accuracy of measurement of 0.8 mm. As an example in Fig.4 the plot of CODs in the horizontal plane calculated by the CODTRACK code is shown.

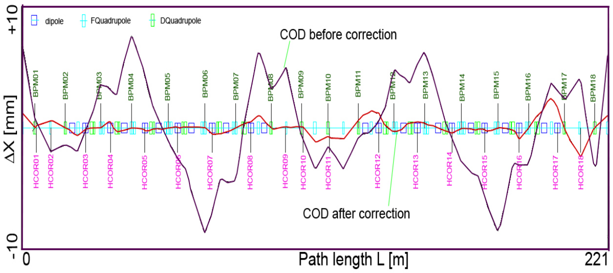

Figure 4: CODs calculated by the CODTRACK code.

There is a possibility graphically to present the statistical distribution of the rms and maximum CODs (see Fig.5). For the corrected CODs the statistical distribution of the strengths of the corrector magnets can be plotted for all correctors. In Fig. 6 the corrector strength distributions for the 18 horizontal correctors are shown. Table 2 summarizes the results of calculations for antiproton (pbar) and Radioactive Ion Beam (RIB) optics in both horizontal and vertical planes. The rms and maximum corrector strength required ("kick angle" in the table) to correct the closed orbit error in each case is given. In determining the maximum corrector strength we have considered the envelope of maximum corrector strength ignoring a few which lie outside this envelope. If we can achieve mentioned level of alignment tolerance for magnets and BPMs, we will be operating the correctors with a maximum strength of 3 mrad giving us enough strength to correct for any unforeseen problem.

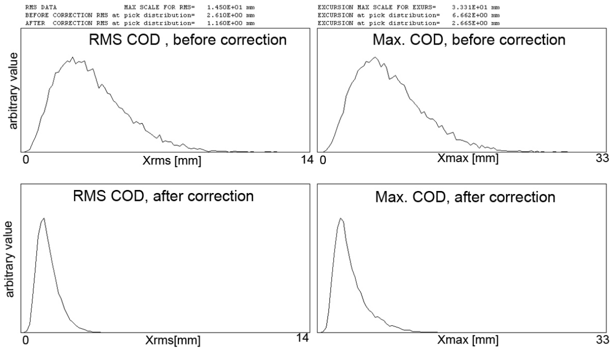

Figure 5: The statistical distribution of the rms and maximum COD values before and after correction.

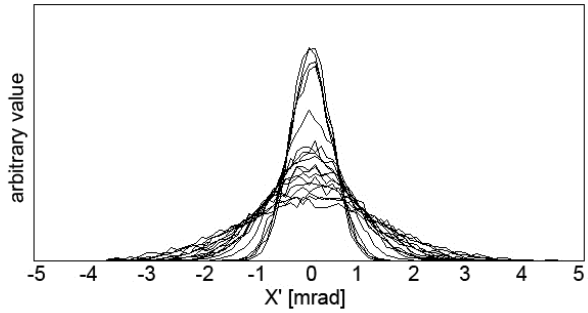

Figure 6: The statistical distributions of the kick angles for the 18 corrector magnets.

Table 2: Calculated COD before and after correction in the horizontal "H" and vertical planes "V". "12(dip)" means 12 correctors integrated in the dipole magnet and "12(sex)" in the sextupole magnets, "6(h/v)" - 6 horizontal/vertical combined corrector magnets are in the long straight sections

optics	Type of correctors	COD rms/max Before cor	After cor	Kick angle rms/max
		mm	mm	mrad
H(pbar)	12(dip)+6(h/v)	7.8 / 18	0.9 / 4.1	0.7 /2.4
V(pbar)	12(sex)+6(h/v)	4.1 /11.2	1.3 / 3.3	1.2 / 4.7
H (RIB)	12(dip)+6(h/v)	6.2/15.2	1.1/2.61	0.61/2.5
V (RIB)	12(sex)+6(h/v)	3.6/9.2	0.61/1.9	0.74/2.81

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