

RESONANCE CORRECTION SYSTEMS FOR JPARC MAIN RING

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Abstract

The injection time for the JPARC Main Ring (MR) according to the basic scenario is about 120ms, which corresponds about 25'000 turns. The particle losses at the Main Ring collimator should be less than 1% from the expected maximum beam power at the injection energy. To keep the particle losses for the Main Ring operation below the limit, the correction systems have been suggested to eliminate possible resonance excitation. The proposed correction schemes allow us to suppress linear and nonlinear resonances, caused by the machine imperfection. The calculated and/or measured field data for main magnets of the ring has been taken into account for this study.

INTRODUCTION

According to the design strategy for the JPARC MR, the particle losses during the injection and acceleration process should be kept at the level of 1% from the beam power at the injection energy. The space charge effect of the low energy beam will play significant role even for the beam power about 100-200kW, which is a goal for the early stage of the MR commissioning. The space charge of the low energy beam will change the betatron tunes of the beam particles [1], so that the particle could be captured into some linear and non-linear resonances, caused by the machine imperfection. In frame of this report we did not analyze the resonances excited by the space charge itself. Only the machine resonances have been studied and correction schemes to suppress these resonances have been proposed. The realistic machine imperfection based on the field measurement, performed for main MR magnets, has been considered.

According to the analysis of the resonance excitation [1] the 'bare' working point of MR has been changed to avoid the linear coupling resonance $Q_x - Q_y = 0$. For the 'bare' working point with the horizontal tune in the range $Q_x = 22 \dots 22.5$ and the vertical tune $Q_y = 20.5 \dots 21$ the following structure resonances $2Q_x = 45$, $Q_y = 21$ and $2Q_x - 2Q_y = 3$ could be excited. Other resonances for this range of the betatron tunes are non-structure ones. The influence of different resonances on the particle motion should be studied and some basic correction schemes should be proposed to eliminate the particle losses.

MR RESONANCE CORRECTION SYSTEM

MR resonance correction system has been proposed to keep under control main resonances for the chosen range of the betatron tunes, in particular, the linear coupling resonance [1,1,43]; the half integer resonances [2,0,44],

[2,0,45], [0,2,41] and [0,2,42]; the normal sextupole resonances [1,2,64], [3,0,67] and [-1,2,19]. The corresponding correction schemes have been analyzed to avoid the particle losses in MR. For this study only the single particle dynamic has been studied for different working point. The beam survival at the MR collimator before and after the correction of the resonances has been simulated by using the symplectic tracking codes COSY Infinity [3] and PTC [4].

Linear coupling resonances

The linear coupling resonance [1,1,43] will be excited by mainly the quadrupole roll around the axis and the vertical axial shift of the sextupole magnets for the chromaticity correction. The skew quadrupole field components of the MR magnets are not considered in frame of this study. The Gaussian misalignment errors of the quadrupole and sextupole magnets with $\sigma_{\text{TILT}} = 3.5e-4$ and $\sigma_{\text{SHIFT}} = 5e-4\text{m}$ (cut= 2σ) have been generated. The symplectic single particle tracking during 1000 turns has been performed for different tunes near the resonance line [1,1,43] by using the 9th order Taylor map. The initial coordinates of the particle x_0, y_0 have been changed ($x_0' = y_0' = 0$). The beam survival at the MR collimator has been used to analyze the resonance effect before and after correction. The effect of the linear coupling resonance for MR before the correction has been observed (Figure 1). The vertical betatron tune in that case has been fixed and equal to $Q_y = 20.78$. The shift of the minimum of the beam survival from the resonance tune is caused by the amplitude dependent tune-shift, produced by the sextupole field nonlinearity used in MR to correct the linear chromaticity.

The correction scheme is based on four skew quadrupole magnets, installed at the beginning and at the end of two 'dispersion-free' MR straight sections, the 'INJ' section and the 'RF/FastExtraction' section. By using these independent skew quadrupole magnets, one can make zero the off-diagonal (2×2) block of the (4×4) transfer symplectic matrix. In that case the linear particle motion is decoupled completely.

The beam survival at the MR collimator with the physical acceptance of 81π mm.mrad has been simulated for different error-sets before and after the correction the linear coupling resonance (Figure 1). The beam emittance at the injection energy is 54π mm.mrad. The obtained results show that after the resonance correction the particle losses, caused by the linear coupling resonance, can be eliminated. The maximum required integrated strength of the skew quadrupole magnets is about $(kL)_{SQ} \sim 0.025\text{m}^{-1}$, which is about 10% from the nominal strength of the MR quadrupole magnets.

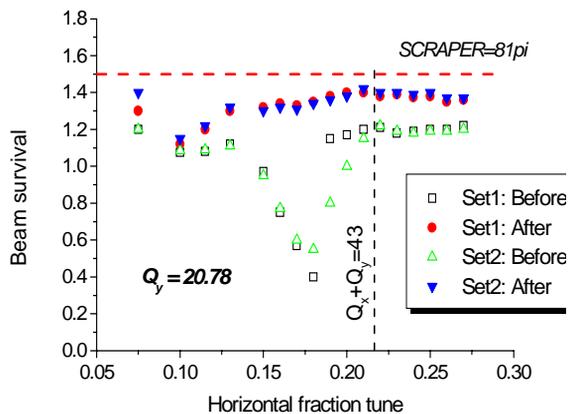


Figure 1: Beam survival at the MR collimator with the physical aperture of 81π before and after correction the linear coupling resonance for different values of the horizontal betatron tunes.

Half-integer resonances

The MR half-integer resonances $[2,0,44]$, $[2,0,45]$, $[0,2,41]$ and $[0,2,42]$ would lead to the ‘beta’ and ‘dispersion’ beating effects near the resonance stop-band and to instability of the particle motion inside of the resonance stop-band. The following main random sources of the half-integer resonances have been introduced into the simulations: errors of the MR quadrupole magnets, quadrupole field components of the MR bending magnets (obtained from the field measurement) and horizontal shift of the MR sextupole magnets. The strength error of the quadrupole magnets with the maximum value $|\Delta kL/(kL)_0| \leq 5e-4$ have been generated by using the uniform distribution. The misalignment of the MR sextupole magnets has been performed to provide the Gaussian distribution with $\sigma_x = 3.5e-4$ m (with the 2σ cut).

The correction of the half-integer resonances should be performed by using the quadrupole trim coils of the quadrupole magnets, located into the dispersion-free straight sections. The proposed correction scheme for the ‘basic’ region of the working point should be able to suppress both harmonics 41 and 42 at the same time (Figure 2). Additionally, the tune variation caused by the introduced errors should be compensated by the half-integer resonance correctors.

The minimum number of the quadrupole correctors to correct the resonance stop-band for two harmonics is just 10 from 45 quadrupole magnets of MR, installed into the straight sections. The short quadrupole magnets and the quadrupole magnets with big beta-functions should not be used for this correction procedure. The remained number of the acceptable quadrupole magnets for the half-integer resonance correction is 25. The required strength of the quadrupole correctors is smaller than 5% from the nominal values. By using this limitation of the strength of the correctors, the ‘beta’ beating parameter for the particular harmonics 44, 45 (horizontal) and 41, 42 (vertical) can be reduced more than 10 times.

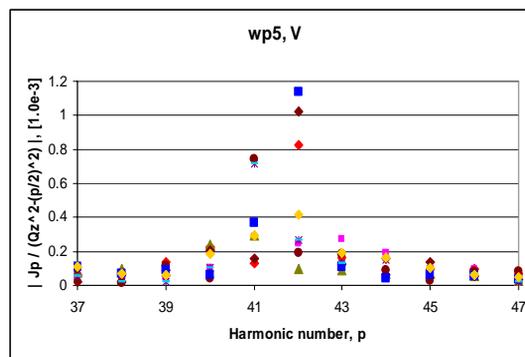


Figure 2: The ‘beta’ beating effect for different harmonic number and different error sets before the half-integer resonance correction (horizontal ‘beta’ beating is not depicted).

Normal sextupole resonances

The normal sextupole resonances $[1,2,64]$, $[3,0,67]$ and $[-1,2,19]$ should be corrected to reduce the uncontrolled particle losses during the injection process. The main sources for excitation these resonances are the chromaticity correction sextupole magnets in combination with the distortion of the MR super periodicity by the injection dog-leg, the sextupole field component of the MR bending magnets and the error of the sextupole strength of each chromatic sextupole magnet. All normal sextupole resonances around the MR working point are the non-structure ones.

Two different correction schemes have been analyzed for the MR lattice. The first scheme is based on the correction the isolated resonance. The second scheme has been studied to perform the effective correction of all three normal sextupole resonances at the same time with minimal nonlinear distortion of the lattice.

To realize the first correction scheme one can use just two sextupole correctors, installed into the dispersion-free straight section (the ‘RF’ section of MR) with the phase advance between them about $n \times 270$ degrees ($n=1,2,\dots$) and near the maximum beta-functions. In that case one can avoid changing the chromaticity and the ‘feed-down’ effect due to the closed orbit distortion. The required strength of the sextupole correctors is about 20% from the nominal value of the chromaticity correction sextupole magnets at the injection energy.

As we know, the compensation only one normal sextupole resonance could lead to excitation other sextupole resonances. This effect can lead to increasing the particle losses after the correction of one separated resonance in the case of the low energy beam with the high beam power. Then for MR another correction scheme has been considered, which allows minimizing the resonance norms of a few resonances at the same time.

This correction scheme is based on the trim coils of the MR sextupole magnets without any additional sextupole correctors. The trim coils should be placed into the MR sextupole magnets so that to provide the minimum

contribution to the linear chromaticity and to correct the resonances by using the minimum strength of the trim coils. The trim coils with appropriate phase advance should be used only for the MR sextupole magnets, located near the minimum of the horizontal dispersion and near the maximum of the beta-functions, ($\beta_x^{3/2}$, $\beta_x^{1/2}\beta_y$).

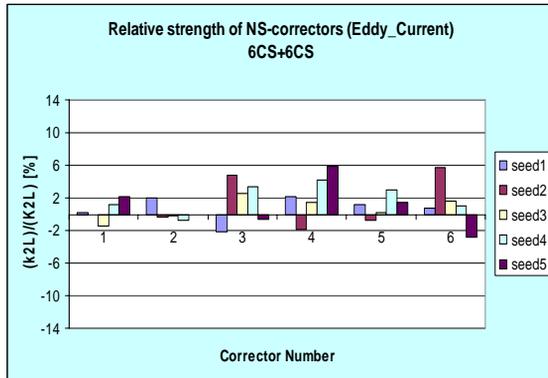


Figure 3: Required strength of the trim coils of the MR sextupole magnets to correct normal sextupole resonances [1,2,64], [3,0,67] and [-1,2,19] at 7GeV energy, including the ‘Eddy’ current effect.

Efficiency of the correction scheme has been checked for different sets of the corresponding errors. The required strength of the ‘distributed’ correctors is less than 3% from the nominal value of the chromaticity correction sextupole magnets. The number of the trim coils is 12 to realize this correction scheme for MR.

Additional effect of the ‘eddy’ current of the MR bending magnets has been introduced into consideration of the normal sextupole resonance excitation. The maximum sextupole component of the MR bending magnets, caused by the ‘eddy’ current, has been observed for the 7GeV energy. The corresponding systematic sextupole component is $(K_2L)_{EC} \sim 0.01m^{-2}$.

To correct the normal sextupole resonances, including the ‘eddy’ current effect of the MR sextupole magnets, the proposed correction scheme has been utilized successfully (Figure 3). The required strength of the ‘distributed’ correctors of MR is about 6% from the nominal values of the chromaticity correction sextupole magnets.

Summary of the resonance correction elements for MR

To control main low order resonances during the MR operation the following correction elements should be used. Excitation of the linear coupling resonance [1,1,43] can be suppressed by using 4 skew quadrupole magnets, installed in two dispersion-free straight sections of MR. In this case one can perform the local de-coupling to eliminate the particle losses at the MR collimator. The half integer resonances [2,0,44], [2,0,45], [0,2,41] and [0,2,42] can be controlled by using 25 trim coils powered

in the MR quadrupole magnets, installed in the dispersion-free straight sections of MR. In principal, the total number of the trim coils, which can be powered to suppress the half integer resonances, can be increased up to 45. The normal sextupole resonances [1,2,64], [3,0,67] and [-1,2,19] can be corrected by using 2 additional sextupole correctors or 12 sextupole magnets of MR with the correction trim coils. All these elements are collected in Table 1.

Table 1: Resonance correction elements for MR

Type of resonance	Type of correction elements	Number / Location
[1,1,43]	Skew QM	4 independent ‘RF’ & ‘INJ’ sections
[2,0,44], [2,0,45], [0,2,41], [0,2,42]	Trim Coils of MR QM	25 trim coils MR straight sections
[1,2,64], [3,0,67] [-1,2,19]	Trim Coils of MR SM	12 trim coils MR arcs

CONCLUSION

The proposed correction schemes allow controlling main low-order resonances. The required strength of the correctors can be kept within the reasonable range. For the MR operation with high beam power it is necessary to study efficiency of the correction schemes in combination with the space charge effects of the low energy beam. If the particle losses caused by the skew sextupole and normal octupole resonances will be observed, the corresponding additional correction elements will be used.

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