POSITION SHUFFLING OF THE J-PARC MAIN RING MAGNETS

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Abstract

The J-PARC 50 GeV main ring has 96 dipole, 216 quadrupole (11 family) and 72 sextupole magnets (3 family) for chromaticity correction. Magnets installation in the tunnel started last year and will be planned to finish by the end of next fiscal year. Field measurements of all magnets finished in March 2006. Deviations for BL, B'L, B"L of dipole (BM), quadrupole (QM) and sextupole magnets (SX) make a COD, β modulation and third integer stopband, respectively. They can be reduced by choosing a pair of magnets with a similar field deviation and by positioning them so as to cancel each other considering betatron phase (shuffling). In this paper, we will report our shuffling scheme and also will show performances expected by the shuffling.

INTRODUCTION

The J-PARC accelerator complex comprises a 400 MeV linac, a 3 GeV rapid cycle synchrotron (RCS) and a 50 GeV main ring (MR). The MR has three fold symmetry, three 116.1 m long straight sections and three 406.4 m long arc sections. The MR has an imaginary γ_t lattice in order to avoid the beam loss during transition crossing [1]. The middle of 3 FODO cells in the arc section do not have a bending magnet so that dispersion function has a peak at the center and negative at the both ends of 3 FODO cells. As a result, the ring has a negative momentum compaction factor. One module comprises 3 FODO cells has horizontal phase advance of 270 deg. One arc section have 8 modules and phase advance of the 6 times of 360 deg, therefore, dispersion function outside of the arc section is zero. The chromaticity correction sextupole magnets with three families (SFA, SDA and SDB) are located in the middle of one module. The each long straight section consists of 3 regular FODO cells and matching sections to the arc section at the both ends. The arc section has four quadrupole family. The long straight section has 7 quadrupole family. A layout of the lattice magnets is shown in Figure 2. Nominal operating tune is shown in Figure 3.

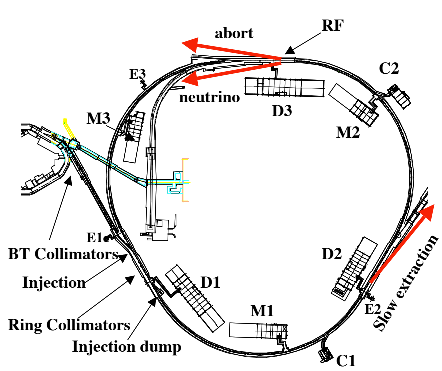

Figure 1: Layout of the MR.

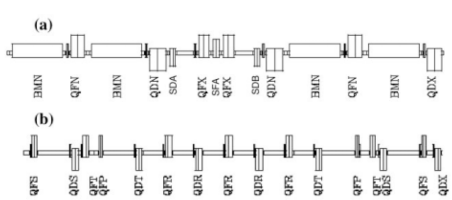

Figure 2: Layout of the lattice magnets. (a): one module in the arc section, (b): long straight section.

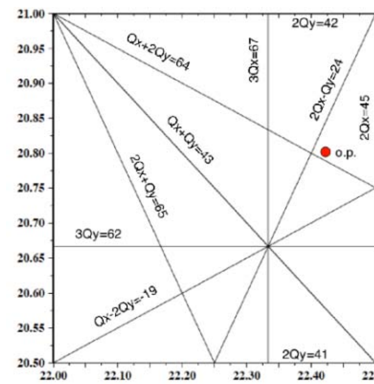

Figure 3: Tune diagram and nominal operating point (o.p.)

Magnetic field measurements for all of the lattice magnets completed in March, 2006 [2]. Deviations from average values for BL, B'L, B"L in the each BM, QM and SX make COD, the modulation of β function and third order stopband, respectively. They can be reduced by choosing a pair of magnets with a similar field deviation and by positioning them so as to cancel each other considering betatron phase (shuffling). We will describe the shuffling scheme and show the obtained performance.

BM SUFFLING

Figure 4 shows measured ΔBL/BL distribution for 96(+1 for a dummy) BMs. The standard deviation σ of ΔBL/BL for 3 GeV and 50 GeV energy is 0.00024 and 0.00061, respectively. The spread for 50 GeV energy is larger than that for the 3 GeV energy. We can not observe any correlation between these two distributions. This seems to be caused by the field saturation effect at a high magnetic field. Larger ΔBL/BL spread makes larger

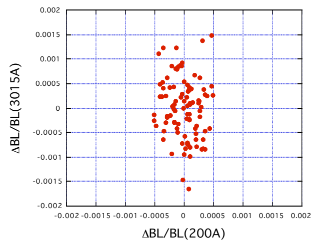

Figure 4: measured BL error of bending magnets.

COD. On the other hand, the COD correction is easier at low energy from the point of view of the limited corrector strength. Therefore we decided to shuffle BMs in order to minimize the COD at 50 GeV energy.

The cod by ΔBL /BL is written as,

$$x_{co}(s) = \frac{\sqrt{\beta(s)}}{2sin\pi\nu}\sum_i \sqrt{\beta_i}\frac{(\Delta BL)_i}{B\rho}\cos(\pi\nu + |\psi(s) - \psi_i|) \quad (1)$$

where, β(s) and ψ(s) are beta function and betatron phase at position s, β_i and ψ_i are beta function and betatron phase at the ith BM, respectively, and v is horizontal tune. Our position shuffling scheme of the BMs is as followed. One module in the arc section has 4 BMs and a horizontal phase advance of 270 deg. Therefore phase advance between the ith and (i+8)th BMs in the arc section is 540 deg. A pair with similar ΔBL at 50GeV energy is chosen and assigned at the ith and (i+8)th BM positions. Contribution to COD by this pair can be cancelled each other from Eq. (1).

The COD made by the ΔBL deviation of all QMs was obtained from the SAD code. The (a) and (b) in Figure 5 show the CODs without shuffling along the whole ring. In this case, BMs are arranged in the ring in serial number order. The COD (b) for 50 GeV is larger than that (a) for 3 GeV, which is due to the difference of ΔBL/BL spread for 50 GeV and 3 GeV energies. The maximum horizontal COD at 50 GeV is roughly 5 mm. As seen in Figure 5 (d), the COD is drastically reduced by the shuffling. The magnitude of COD (c) at 3 GeV is same as (a) without shuffling. This is due to no correlation between ΔBL/BL distributions at 3 GeV and 50 GeV (see Figure 4).

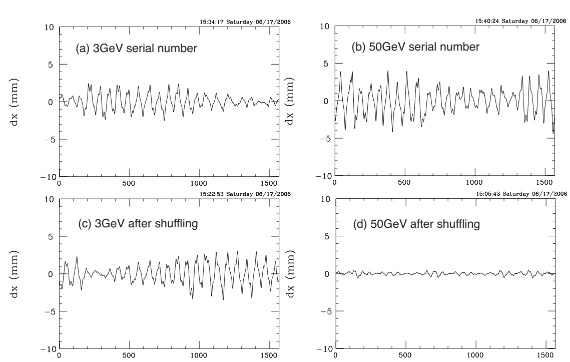

Figure 5: COD by ΔBL/BL spread of the BMs.

QM SHUFFLING

Figure 5 shows measured ΔB′L/B′L distributions of the QFN family. The standard deviation σ of ΔB′L/B′L of for 100A and 1100A are 0.00027 and 0.00046, respectively. The electric currents of 100A and 1100A correspond to roughly 3 GeV and 40 GeV energies. The spread for 1100 A is larger than that of the 100A. We estimate that it is also caused by the field saturation. The magnets in other family show a similar tendency.

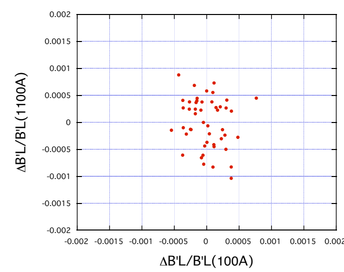

Figure 6: Measured ΔB'L/B'L distribution for the QFN.

The deviation ΔB'L/B'L of the quadrupole magnets makes a half integer stop band and causes β_x and β_y modulation. The horizontal and vertical stop band J_{Px} and J_{Py} are given by

$$J_{Px} = \frac{1}{2\pi}\sum_i \beta_{xi}\frac{(\Delta B'L)_i}{B\rho}\exp(-iP_x\phi_{xi}) \qquad (2)$$

$$J_{Py} = \frac{1}{2\pi}\sum_i \beta_{yi}\frac{(\Delta B'L)_i}{B\rho}\exp(-iP_y\phi_{yi}) \qquad (3)$$

where Px and Py are horizontal and vertical harmonic numbers, ϕ_{xi} and ϕ_{yi} are the horizontal and vertical position angles in the ring for the ith quadrupole magnet.

A pair of magnets in the same family are placed so as to cancel J_{Px} for the QF family and J_{Py} for the QD family. For example, in case of the QFN, a pair with the same |ΔB’L/B’L| and opposite sign are arranged at the ith and the (i+4)th positions with 540 deg horizontal phase advance. The shuffling was performed for the field data corresponding to 40-50 GeV, since the spread of Δ′BL/B′L at the high field is larger that of the low field as shown in Figure 6.

Figure 7 shows the β-modulation Δβ/β after the shuffling of all family, which were calculated by the SAD code. The calculated β-modulation is less than 1% and that for 40 GeV is slightly less than that for 3 GeV.

SEXTUPOLE SHUFFLING

The deviation ΔB″L/B″L of the sextupole magnets for the chromaticity correction excites the third order resonance. The related harmonics can be reduced by the position shuffling of the sextupole magnets. The slow extraction using the third integer resonance ($3Q_x$=67) has

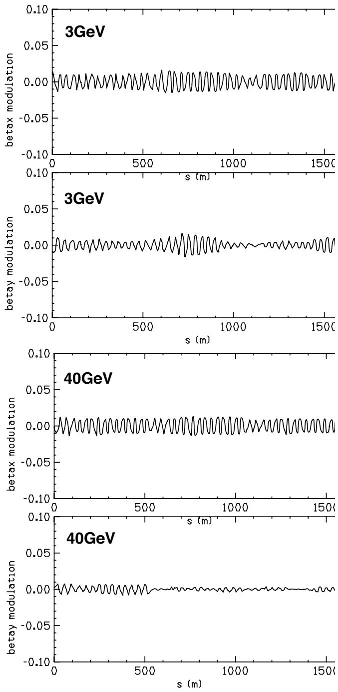

Figure 7: The βx and βy modulations after shuffling.

been adopted for the MR. The shuffling scheme was determined to minimize the 67th harmonics at the operation energy for the slow extraction. Figure 7 shows the measured ΔB″L/B″L distribution for 50A and 200A, which roughly correspond to 3 and 30 GeV energies, respectively. This distribution shows the correlation between them. Similar tendency is seen also for the 400A. The standard deviation σ of ΔB″L/B″L for 50A, 200A and 400A are 0.00096, 0.00075 and 0.00089, respectively.

Sextupole field measurements were divided into 3 batches with each 24 magnets. The 24 magnets in each batch were assigned in the same arc. These assigned magnets are classified into the SFA, SDA and SDB family.

Fourier amplitude δ and the phase ξ of $3Q_x=P_x$ is given by

$$\delta\, e^{i\xi} = \frac{\sqrt{2}}{24\pi}\sum_i \left[\frac{B''L}{B\rho}\beta_x^{\frac{3}{2}}\right]_i \times e^{i\Phi_i} \qquad (4)$$

$$\Phi_i = 2\pi[3\mu_x - (3Q_x - P_x)\frac{\theta_i}{C}] \qquad (5)$$

where μ_x is the ring tune, θ_i is the angle of the ith magnet, and C is the circumference of the ring. A pair of magnets with the similar ΔB″L/B″L in the classified family is placed so as to cancel δ in Eq. (4) each other.

Table 1: Fourier amplitude δ of $3Q_x$=67 resonance.

current (A)	50	200	400
δ (serial number order)	0.0019	0.0016	0.0033
δ (after shuffling)	0.0007	0.0003	0.0009

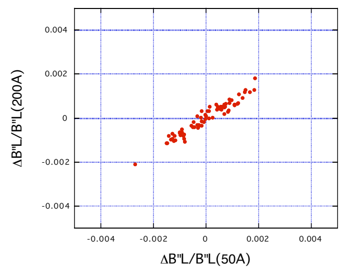

Figure 8: Measured field error distribution of sextupole magnets.

Table 1 is the comparison of the Fourier amplitude δ obtained by the arrangement of the serial number and the position shuffling above mentioned. The amplitude δ is reduced by the shuffling.

CONCLUSIONS

Position shuffling for the bending, quadrupole and sextupole magnets has been performed from the results of field measurements and the installation of all magnets into the tunnel has started.

The COD caused by the deviation ΔBL/BL of the BMs is reduced from 5 mm to 0.4 mm at a high energy by the shuffling.

The shuffling for the quadrupole magnets has been performed so as to reduce the half integer stop band each family. Resultant β-modulation is ~1% at the nominal operating tune.

Sextupole shuffling reduces the amplitude of $3Q_x$=67 resonance by several factor.

ACKNOWLEDGMENT

The authors would like to thank S. Ohnuma for his helpful advice on the shuffling strategy.

REFERENCES

[1] Accelerator Group JAERI/KEK Joint Project Team, "Accelerator Technical Design Report for J-PARC", KEK Report 2002-13, March 2003.

[2] K. Niki, K. Ishii, Y. Nemoto, E. Yanaoka and M. Muto, "Results of Field Measurements for J-PARC Main Ring Magnets", these proceedings.