POSITION SHUFFLING OF THE J-PARC MAIN RING MAGNETS


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 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.

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 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 SHUFFLING

Figure 4 shows measured ∆BL/BL distribution for 96(+1 for a dummy) BMs. The standard deviation σ of ∆BL/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 ∆BL/BL spread makes larger
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 $\Delta BL/BL$ is written as,

$$x_i(s) = \frac{\beta(s)}{2\sin \pi v} \sum \sqrt{\beta} \frac{(\Delta BL)}{B_0} \cos(\pi v + \psi(s) - \psi_0) \tag{1}$$

where, $\beta(s)$ and $\psi(s)$ are beta function and betatron phase at position $s$, $\beta$, and $\psi_0$ are beta function and betatron phase at the $i$th 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 $i$th and $(i+8)$th BMs in the arc section is 540 deg. A pair with similar $\Delta BL$ at 50 GeV energy is chosen and assigned at the $i$th 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 $\Delta BL$ 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 $\Delta BL/BL$ 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 $\Delta BL/BL$ distributions at 3 GeV and 50 GeV (see Figure 4).

**QM SHUFFLING**

Figure 5 shows measured $\Delta B'L/B'L$ distributions of the QFN family. The standard deviation $\sigma$ of $\Delta B'L/B'L$ 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.

**SEXTUPOLE SHUFFLING**

The deviation $\Delta B'L/B'L$ of the quadrupole magnets makes a half integer stop band and causes $\beta_x$ and $\beta_y$ modulation. The horizontal and vertical stop band $J_{px}$ and $J_{py}$ are given by

$$J_{px} = \frac{1}{2\pi} \sum_i \beta_x \frac{(\Delta B'L)}{B_0} \exp(-ipx \phi_{ix}) \tag{2}$$

$$J_{py} = \frac{1}{2\pi} \sum_i \beta_y \frac{(\Delta B'L)}{B_0} \exp(-iphy \phi_{iy}) \tag{3}$$

where $Px$ and $Py$ are horizontal and vertical harmonic numbers, $\phi_{ix}$ and $\phi_{iy}$ are the horizontal and vertical position angles in the ring for the $i$th 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 $\Delta B'L/B'L$ and opposite sign are arranged at the $i$th 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 $\Delta B'L/B'L$ at the high field is larger than that of the low field as shown in Figure 6.

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

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REFERENCES


Table 1: Fourier amplitude $\delta$ of $3Q_x=67$ resonance

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<th>Current (A)</th>
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<td>0.0016</td>
<td>0.0033</td>
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<td>$\delta$ (after shuffling)</td>
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