INFLUENCE OF NONLINEAR MULTIPOLE FIELDS ON BEAM LOSS IN THE SLOW EXTRACTION FROM JHF MAIN RING

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Abstract

A third-integer slow extraction system for the 50-GeV main ring of the proposed Japan Hadron Facility (JHF) has been designed. The key issue for the slow extraction is to reduce the beam loss to 1% level from the point of view of radiation safety. Beam simulations have been done to study influence of multipole fields in lattice magnets on the beam loss.

1 INTRODUCTION

The 50 GeV main ring in the Japanese Hadron Facility (JHF) provides a beam of 10 μA protons to K-arena experimental hall by a slow extraction. The beam is debunched after acceleration, and is extracted over a period of 0.7 s. In a design of the slow extraction, beam loss must be less than 1% level, which is required from the radiation safety. There are two schemes for the slow extraction, a third-integer and a half-integer ones. A third-integer slow extraction for the 50-GeV main ring has been mainly studied so far[1, 2, 3].

The beam loss in the slow extraction is due to 1) particles' hit on electrostatic-septum (ESS) wires, 2) particles' hit on magnetic septa, and 3) particles which are not extracted and remained in the ring. Main beam loss is caused by 1). Moreover, there are two kinds of particles' hit to the ESS wires: head-on hit (the entrance-end wire is hit) and side hit (the side of the wires is hit). In the head-on hit the amount of beam loss depends on a particle density near the wires. To reduce it, the step size should be chosen to be as large as possible within the gap length of the ESS. The step size is influenced on the multipole components in lattice dipole and quadrupole magnets. This effect has been examined by beam simulations in this paper. In the side hit the loss depends on the angular spread of the particles near the wires as well as the particle density. A proposal to reduce the beam loss due to this process is reported in ref. [1].

2 LAYOUT OF SLOW EXTRACTION

The JHF 50-GeV main ring has an imaginary transition-γ lattice and four long straight sections (LSS's), each of which is 60 m long [1]. Each LSS consists of four FODO cells. An electrostatic septum is installed in one of LSS's, and five magnetic ones (MS-1$\sim$5) in another LSS. These LSS's are apart from each other by 1/2 circumference.

In the original design, the beam optics functions are β_x = 28 m, α_x = 2.6, η_x = 0.29 m at the entrance of the ESS. The large α_x-value brings about a problem that two of the three arms coming out from the separatrix cross the ESS wire. We have modified the beam optics of the LSS during the extraction process: we added two quadrupole magnets in the LSS and reduced the α_x value. The resulting beam-optics functions at the entrance of the ESS are β_x = 25 m, α_x = 0.5, η_x = 0.35 m. The ESS wires are positioned so that $x = -43$ mm at the entrance end; the extracted beam is kicked inward. Four bump magnets produce an orbit with (-15 mm, 0 mrad) at the entrance of the ESS. The betatron tunes (Q_x, Q_y) is approached from (21.85,15.4) to the resonance (65/3,15.4) by ramping the lattice quadrupole magnets. The horizontal and vertical chromaticities are set to zero by 72 sextupole magnets in 3 families. Twelve sextupole magnets are used to excite the resonance. These sextupole magnets are classified into two families. In each family the six magnets are divided into three pairs. A pair of magnets are located at diametrically opposite positions in the ring and excited by currents with reverse directions.

3 BEAM-LOSS CALCULATIONS AT THE ESS WIRES

3.1 Beam Simulation

A computer code to simulate the slow-extraction process has been developed. This code executes multi-particle tracking in a x-x'-y-y'-$\Delta p/p$ phase space using transfer matrices of the lowest order. A thin lens approximation is used for sextupole and higher order fields. The initial beam distributions are assumed to be a uniform one in a four-dimensional ellipse (x, x', y, y') and a parabolic one for $\Delta p/p$. In an initial condition of the beam, the horizontal and vertical emittances are 6.1 π mm·mrad, and the momentum spread is $\pm$0.23%, in which 2000 particles are distributed. The turn number for the extraction is limited by cpu time to be several thousands. In the simulations, the ESS length is assumed to be 1.5 m and the wire thickness to be 0.1 mm. The maximum turn separation is chosen so as not to exceed $\sim$20 mm (for the ESS-gap length of 25 mm). Minimum beam loss can be found by changing the ESS angle.

3.2 Multipole Fields in the Lattice Magnets

The ring has 96 dipole (D) magnets and 176 quadrupole (Q) magnets in 8 families. Horizontal- and vertical-full

Table 1: Multipole components in the D-magnet

By [kG]	+18.999
$\mathrm{d}^2B_y/\mathrm{d}x^2$ [kG/cm^2]	-2.1356×10^{-3}
$\mathrm{d}^4B_y/\mathrm{d}x^4$ [kG/cm^4]	$+4.7208 \times 10^{-5}$
$\mathrm{d}^6B_y/\mathrm{d}x^6$ [kG/cm^6]	-2.5716×10^{-4}
$\mathrm{d}^8B_y/\mathrm{d}x^8$ [kG/cm^8]	-1.0599×10^{-4}

Table 2: Multipole components in the Q-magnet

$\mathrm{d}By/dx$ [kG/cm]	+1.9998
$\mathrm{d}^5B_y/\mathrm{d}x^5$ [kG/cm^5]	-5.2030×10^{-5}
$\mathrm{d}^9B_y/\mathrm{d}x^9$ [kG/cm^9]	-1.5799×10^{-4}
$\mathrm{d}^{13}B_y/\mathrm{d}x^{13}$ [kG/cm^{13}]	$+1.3534 \times 10^{-3}$
$\mathrm{d}^{17}B_y/\mathrm{d}x^{17}$ [kG/cm^{17}]	-4.4400×10^{-2}

apertures of the D-magnets are 200 mm and 106 mm, respectively. The field strength is 1.9 T. The bore diameter of the quadrupole magnets is 126 mm. The field gradient is 20 T/m. The D- and Q-magnets were designed by the two dimensional code POISSON [1]. The multipole components at extraction energy of 50 GeV are listed in Table 1 and 2.

3.3 Beam Losses with Multipole Fields in the Magnets

Two type of tune approach to the resonance were conducted in the simulation: 1) the Q_x approaches from a higher value to the resonance ("normal tune ramping"); 2) the Q_x approaches from a lower value to the resonance ("reverse tune ramping"). For the normal tune ramping, Fig.1-a) shows a phase space plot of a single particle. In this case, the sepratrix is rotated by 18° from the bump orbit in the normalized phase space. This is necessary to deliver the particles inward for the MS-1. In the reverse tune ramping, it is possible to set the extracted beam in parallel to the closed orbit (Fig. 1-c)). The tune value for the injection can be also chosen above the resonance line. After acceleration, the tune decreases, crossing the resonance, and

Table 3: Beam loss at the ESS wires

	beam loss
normal tune ramping	
no multipole field	1.3%
multipole fields in Q-mag.	1.4%
multipole fields in D-mag.	4.0%
multipole fields in Q+D-mag.	3.7%
reverse tune ramping	
no multipole field	1.0%
multipole fields in Q-mag.	1.0%
multipole fields in D-mag.	0.7%
multipole fields in Q+D-mag.	0.8%

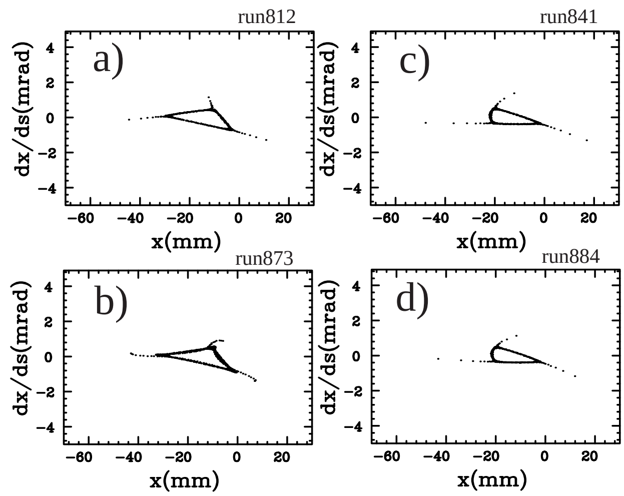

Figure 1: Single-particle motions in x-x' phase space at the entrance of the ESS: a) normal tune ramping, no multipole field, b) normal tune ramping, multipole fields in the D-magnets, c) reverse tune ramping, no multipole field, d) reverse tune ramping, multipole fields in the D-magnets.

then approaches the resonance line. The cross of the third-order resonance would not cause a serious problem, if it is quickly done.

The beam losses calculated by the tracking simulation are summarized in Table 3. When the multipole field is not included in the Q- and D-magnets, the beam loss for the reverse tune ramping is better than that for the normal tune ramping, since the distance between the ESS and an unstable fixed point used for the extraction for the reverse tune ramping is larger than that of the normal tune ramping. The influence of the multipole fields in the magnets on the beam loss is small in the reverse tune ramping. In the normal tune ramping, the loss is large if the D-magnets have multipole fields. This large loss is due to decrease of the step size. We know the following information from further studies:

- in the multipole field, the main part that causes the large loss is the sextupole component;
- when the sextupole strength for the chromaticity correction is half of the full correction, the beam loss decreases to 1% level;
- for the normal tune ramping, a horizontal-tune shift with the multipole field becomes small near the resonance than that with no multipole field (compare ○ and △ in Fig. 2).

From above results, we estimate that the decrease of the step size is caused by an amplitude dependent tune shift due to a higher order effect of the sextupole fields in the dipole and the chromaticity-correction magnets [4].

We tried the following two ways to reduce the beam loss. First, the sextupole strength to excite the resonance is slightly increased to obtain a larger step size. This decreases the beam loss to 2% level. But stronger field causes the step size which exceeds the gap length of the ESS. Sec-

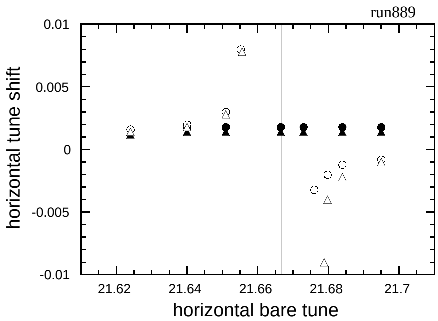

Figure 2: Horizontal-tune shift from the bare tune as a function of the bare tune. closed triangle: no harmonic sextupole field and no multipole field in the D-mag., closed circle: no harmonic sextupole field and multipole fields in the D-mag., open triangle: harmonic sextupole field and no multipole field, and open circle: harmonic sextupole field and multipole field. Tune shift was obtained from a power spectrum of a single particle.

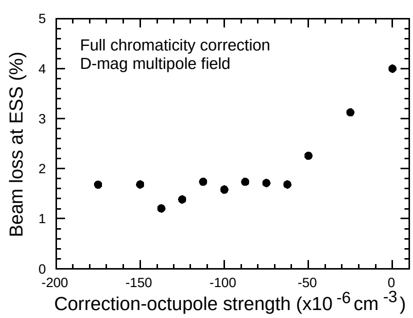

Figure 3: Beam losses at the ESS wires as a function of correction-octupole strength $B'''L/B_0\rho$ (sum of two magnets).

ond, a pair of octupole magnets with the same strength and polarity are added on the opposite side in the ring. Figure 3 shows the beam losses as a function of the octupole strength. The beam-loss increase is compensated by the octupole strength $B'''L/B_0\rho = -138 \times 10^{-6}$ cm^{-3}.

3.4 Octupole Field in the Quadrupole Magnets

A real Q-magnet may have an octupole field, which are generated from an imperfect quadrant symmetry of the magnet. We conducted the simulation to examine the effect of the octupole field in the Q-magnets. The octupole field is added in the multipole fields of the Q-magnet shown in Table 2. The tune is ramped from a higher value to the resonance. Figure 4 shows single-particle motions in x-x' space. In a), octupole field in the Q-magnet is $+1.5 \times 10^{-4}$ kG/cm^3. The step size is very small, as a result, the beam loss is very large 11%. In b), octupole field is -1.5×10^{-4} kG/cm^3. The step size is too large, and arms from the separatrix are bent. Particles from two arms are extracted. Two octupole magnets are placed on the opposite side in the ring. For the condition of a), the beam loss decreases to 1.7% by the octupole strength $B'''L/B_0\rho = -113 \times 10^{-6}$ cm^{-3} (sum of the two magnets).

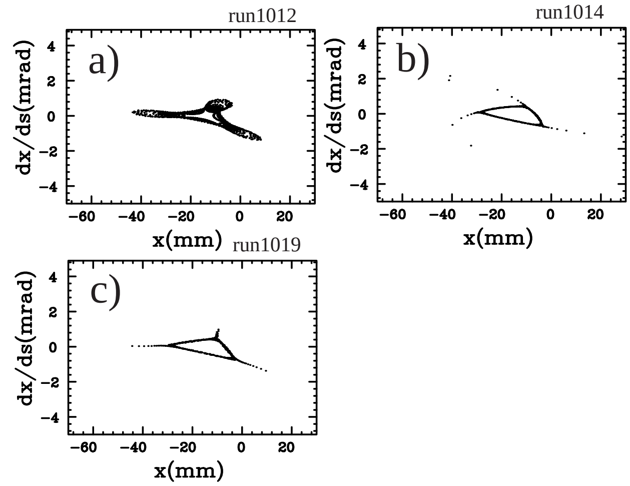

Figure 4: Single-particle motions in x-x' phase space: a) octupole strength $+1.5 \times 10^{-4}$ kG/cm^3 in the Q-magnets, b) octupole strength -1.5×10^{-4} kG/cm^3 in the Q-magnets, c) octupole correction for a).

4 CONCLUDING REMARKS

We have designed a scheme of the third-integer extraction from the 50-GeV ring. The beam losses at the ESS wires were calculated by the tracking simulation. For the normal tune ramping, the loss becomes large with the multipole fields in the D-magnets. This loss-increase is due to decrease of the step size. This is caused by the sextupole fields in the D-magnets and the chromaticity correction magnets. This loss is decreased to 1% level by the octupole correction. The beam-loss increase due to the octupole fields in the quadrupole magnets can be also reduced by the octupole correction.

5 ACKNOWLEDGMENT

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6 REFERENCES

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