DESIGN STUDY OF THE SLOW-EXTRACTION SYSTEM FOR THE JHF 50-GeV MAIN RING

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Abstract

A slow extraction system for the 50-GeV main ring of the Japan Hadron Facility (JHF) has been designed. At a current version of the lattice the ring has four 60-m-long straight sections. In two of them, which are apart from each other by 1/2 circumference, are used for septa: one is for an electrostatic septum, and the other for five magnetic ones. Beam simulations have been done to compare the performances of the third-integer resonance technique and the half-integer resonance one.

1 INTRODUCTION

The JHF 50-GeV main ring for which the present slow-extraction system was designed has four long straight sections (LSS's), each of which is 60 m long [1, 2]. An electrostatic septum (ESS) is installed in one of LSS's, and five magnetic ones in another LSS. These LSS's are apart from each other by 1/2 circumference. Such a long-distance arrangement is due to that of the deflection angle in the ESS is small (0.2 mrad in a 1.5-m-long, 6.8-MV/m electric field); if all the septa are packed into one LSS, the separation of the extracted beam from the circulating one is poor. The ESS located far away (in this sense we call it a preseptum) yielded a better beam separation at the entrance of the first magnetic septum and enabled us to insert a 1-mm-thick septum. Beam simulations have been done for two schemes: third-integer resonance extraction and half-integer resonance one. This paper describes the layout of the extraction devices, beam simulation results, and comparison between the two extraction schemes.

2 LAYOUT OF EXTRACTION DEVICES

The layout of the LSS for the preseptum is sketched in Fig. 1. The preseptum is placed at the exit of a focusing quadrupole magnet, because the β-function (β_x) is large there and the step size is large accordingly. This LSS has two special quadrupole magnets (QFT2's), which solve a difficulty occurring at the third-integer resonance. Without the QFT2 magnets the beam optics functions are β_x = 28 m, α_x = 2.6, η_x = 0.29 m at the entrance of the preseptum. The large α_x-value brings about a problem that two of the three arms coming out from the separatrix cross the septum wire, and hence the particles on the both arms are extracted. A means of settling the problem is to modify the beam optics of this LSS during the extraction process (slow-extraction mode); the QFT2's are excited, and the field gradients of the lattice

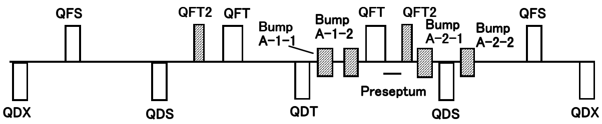

Figure 1: Layout of the preseptum and the bump magnets (A group). The QFT2 quadrupole magnets are installed only in this LSS.

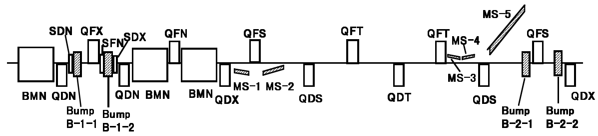

Figure 2: Layout of the magnetic septa (MS-1 through MS-5) and the bump magnets (B group).

quadrupole magnets are different from those in the other LSS's. In the slow extraction mode, the LSS is matched to the adjacent arcs: the beam-optics functions are continuous at the LSS ends; the phase advance over the LSS is the same as that in the other LSS's ($\Delta\mu_x = 2\,\pi$, $\Delta\mu_y = \pi$). We thereby reduced the α_x value; the resulting beam-optics functions at the entrance of the preseptum are β_x = 25 m, α_x = 0.5, η_x = 0.35 m.

The preseptum wires are positioned so that (x, x') = (-43 mm, -0.25 mrad) at the entrance end; the extracted beam is kicked inward. Four bump magnets (A group) produce an orbit with (-15 mm, 0 mrad) at the entrance of the preseptum.

The septa other than the preseptum are five magnetic ones (MS-1 $\sim$ MS-5); their layout is shown in Fig. 2 along

Table 1: Parameters of the preseptum.

location	LST3.2
length	1.5 m
deflection angle	-0.2 mrad
electric field	6.79 MV/m
gap (wire-cathode)	25 mm
voltage	0.170 MV

Table 2: Parameters of magnetic septa

septum magnet	MS-1	MS-2	MS-3	MS-4	MS-5
location	LST1	LST2	LST3.2	LST3.2	LST2.2
$\theta_{\rm kick}$ (mrad)	-1.8	-1.4	9.0	3.0	64.0
B (tesla)	0.133	0.068	0.665	0.222	1.673
length (m)	2.3	3.5	2.3	2.3	6.5
gap (mm)	40	40	40	40	40
NI (kA·turns)	4.23	2.16	21.2	7.05	53.2
$t_{\rm septum}$ (mm)	1	2	10	10	30
$J_{\rm septum}$ (A/mm^2)	106	27	53	18	44

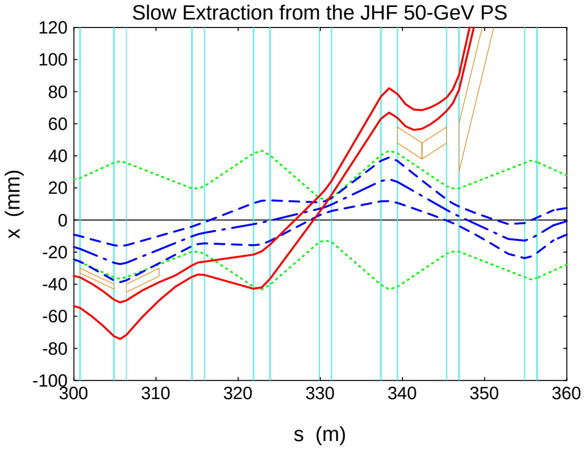

Figure 3: Beam envelopes in the long straight-section: 1) 3-GeV injected beam (dotted lines), 2) 50-GeV circulating beam (dashed lines), and 3) 50-GeV extracted beam (solid lines). The coils of the magnetic septa are indicated by parallelograms, and the edges of the quadrupole magnets by vertical lines.

with bump magnets (B group). The phase advance between the preseptum and the first magnetic septum MS-1 is 3662°; the extracted particles are kicked inward in MS-1 as well as in the preseptum. The particles receive further inward kick in MS-2 and outward kick in MS-3, -4, and -5. The bump orbit is such that (x, x') = (-19.75 mm, -2.11 mrad) at the entrance of the MS-1 septum.

Figure 3 shows beam envelopes in the long straight section for MS-1 through MS-5. The envelopes plotted here are 1) 3-GeV injected beam (ε = 54 π mm·mrad, $\Delta p/p$ = $\pm$0.42%, COD = $\pm$1 mm), 2) 50-GeV circulating beam (ε = 6.1 π mm·mrad), 3) 50-GeV extracted beam. The parameters of the septa are listed in Tables 1 and 2. At the exit of the final septum MS-5 the beam is separated so far from the equilibrium orbit that it will not hit the yoke of the quadrupole magnet: the half width of the yoke is 410 mm, and the particles distribute in the range of x = 445 $\sim$ 472 mm.

3 BEAM SIMULATION

The key issue in the slow-extraction design is to reduce the beam loss at less than 1% level. The beam loss is mainly caused at the wires of the preseptum. 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 the 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 the beam simulation, the preseptum length is assumed to be 1.5 m and a thickness of the wires 0.1 mm. The minimum beam loss can be found by changing the preseptum angle.

3.1 Third-integer extraction

In the simulation, the horizontal position of the preseptum wires is set to -43 mm. The horizontal and vertical emittances are 6.1 π mm·mrad, and the momentum spread is $\pm$0.23%. The horizontal betatron tune is approached to the resonance 65/3 by ramping the lattice quadrupole magnets (QFN's). The horizontal and vertical chromaticity is set to zero by sextupole magnets for the chromaticity correction. Twelve sextupole magnets used to excite the resonance are distributed in the missing dipole magnet sections. 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. The zero-th harmonic component is thereby kept. The angle of the separatrix can be rotated by changing sextupole-field strengths.

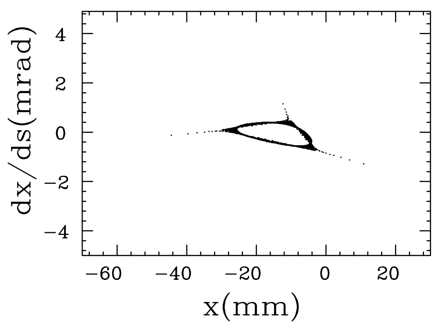

Figure 4: Phase space plot of a single particle at the entrance of the preseptum.

Figure 4 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. The horizontal betatron tune is approached to the resonance of 21.666 from a higher value (normal tune ramping). The position and the angle of the bump orbit are -15 mm and 0 mrad at the preseptum.

Table 3: Beam loss at the preseptum in the third-integer extraction.

	beam loss
normal tune ramping	
fixed bump	1.3%
dynamic bump	0.9%
reverse tune ramping	
fixed bump	1.0%
dynamic bump	0.8%

The angular spread near the wires is about 0.7 mrad. The calculated minimum beam loss is 1.3%.

There are two kinds of particles' hit to the preseptum wires. One is the head-on hit: the entrance-end wire is hit. This 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 preseptum. The other hit is such that particles hit the side of the wires. In this case, the loss depends on the angular spread of the particles near the wires as well as the particle density. In the present design, the preseptum is placed at the position with the small dispersion (0.35 m), and the chromaticity is set to zero. In this case, the angular spread is mainly caused by the emittance of the circulating beam, because the separatrix shrinks with the tune shift. This angular spread can be decreased by varying the angle of the bump orbit during the extraction (dynamic bump). In the simulation, the angle of the bump orbit is varied from -0.8 mrad to 0.65 mrad, and the position is kept at -15 mm. The angular spread has been reduced by varying the bump orbit. As a result, the beam loss at the preseptum wires decreased to 0.9%. The emittance of the extracted beam integrated over the extraction period has decreased by a factor of about 3.

If the horizontal tune approaches the resonance value from a lower value, it is possible to set the extracted beam in parallel to the closed orbit. The tune value during acceleration is 21.85, higher than the resonance of 21.666. Hence, after acceleration, the tune decreases, crossing the resonance, and then approaches 21.666 (reverse tune ramping). The cross of the third-order resonance would not cause a serious problem, if it is quickly done. We performed a beam simulation under this scheme. In this case, the beam loss at the preseptum wires is 1.0%, which is less than 1.3% in the normal tune ramping case. Also, the loss is decreased further by the dynamic bump, in which the beam loss is 0.8%. The results described above are summarized in Table 3.

3.2 *Half-integer extraction*

We also performed the beam simulation for half-integer resonance extraction. The position of the preseptum wires is set to -43 mm. The beam-optics functions are set to β_x = 25 m, α_x = 0.5, η_x = 0.35 m at the entrance of the preseptum. The horizontal and vertical emittances are 6.1 π mm·mrad, and the momentum spread is $\pm 0.23\%$. The horizontal betatron tune is approached from the 21.85 to the resonance 43/2. The horizontal and vertical chromaticity is set to zero. Four quadrupole and four octupole magnets for the extraction are distributed in the missing dipole magnet sections. The magnets are paired in the same manner as the 12 sextupole magnets in the third-integer extraction.

Figure 5 shows a phase space plot of a single particle by the simulation. A preliminary result shows that the minimum beam loss is in 1% level, which is almost the same as that in the third-integer extraction.

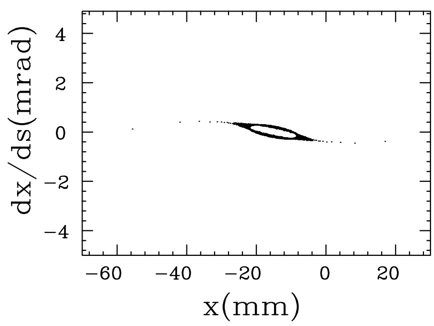

Figure 5: Phase space plot of a single particle at the entrance of the preseptum.

4 CONCLUDING REMARKS

We have designed a scheme of the extraction from the 50-GeV ring. The important issue is to minimize the beam loss. Simulations show that the beam loss at the preseptum wires is 1% level for both third- and half-integer extraction. We will try to reduce the loss further, and improve the simulation for more precise estimation (the ripples and the multipole components of the magnetic fields should be taken into account). From the point of view of clearing the ring of the beam, the third and half-integer resonance will be compared. The decision which resonance to adopt will be made after comparing overall performances.

5 ACKNOWLEDGMENT

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6 REFERENCES

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