DESIGN OF SMALL-BEAM LOSS SLOW EXTRACTION IN A HIGH INTENSITY 50-GEV PROTON SYNCHROTRON

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Abstract

The high intensity 50-GeV main ring of the JAERI/KEK Joint Project has three fold symmetry lattice. Slow extraction system has been designed for the main ring. 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 the beam loss at the electrostatic septum wires. This result shows the beam hit rate on the septum wires is 1%. The R&D electrostatic septum has been constructed and tested. The magnetic septa housed in the vacuum chambers are under designed.

1 INTRODUCTION

The 50 GeV main ring in JAERI/KEK Joint Project[1] has an imaginary transition-γ and three fold symmetry lattice. The main ring provides a beam of 15 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[2, 3, 4]. 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. In the side hit the loss depends on the angular spread of the particles near the wires as well as the particle density. On the basis of these things, the slow extraction system has been designed. The beam loss at an electrostatic septum were examined by the tracking simulation. Present status of the design for the ESS and magnetic septa (SMs) is also reported in this paper.

2 SLOW EXTRACTION SCHEME

In the previous version, the 50-GeV main ring had four 60 m-long straight section[2]. In the present design, the main ring has three-fold symmetry lattice. Characteristics of this ring from the point of view of slow extraction are as followed;

- The long straight section (LSS) for the slow extraction has 116 m. The ESS, SMs and bump magnets can be placed in this LSS.
- The LSS have short straight sections with almost zero α_x between two focusing quadrupole magnets. The ESS are placed at one of the short straight sections.
- The η_x and η'_x are zero in the LSS.

The horizontal betatron tunes Q_x is approached from below of the resonance 67/3 to the resonance by ramping focusing quadrupole magnets (QFNs) in the arc sections. The horizontal and vertical chromaticities are set to zero by 72 sextupole magnets in 2 families. Eight sextupole magnets are used to excite the resonance. These sextupole magnets are classified into two families in order to be able to rotate the separatrix. They does not excite the 0th harmonic component for any current.

The beam optics functions at the entrance of the ESS are β_x = 34.5 m, and α_x = 0.02. The ESS wires are positioned so that $x = -55$ mm at the entrance end; the extracted beam is kicked inward by -0.2 mrad. The betatron phase between the ESS and the 1st SM is 243 degree, which makes separation of 3.4 mm between kicked and not kicked particles at the ESS. The arrangement of the septa and the bump magnets and β-function in the LSS is shown in Figure 1. Figure 2 shows the beam trace of the extracted and circulating particles. The initial condition at ESS entrance is $x = -55$ mm and $x' = -1.54$ mrad for both particles.

3 BEAM-LOSS CALCULATIONS AT THE ESS WIRES

The computer code to simulate the slow-extraction process 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 ±0.31%, in which 2000 particles are distributed. The resonant sextupole strength is chosen so as to be the step size less than

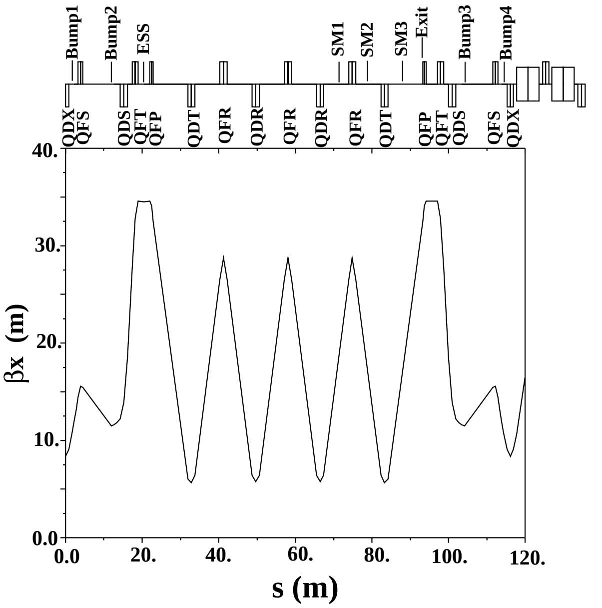

Figure 1: Layout of the extraction device and β-function.

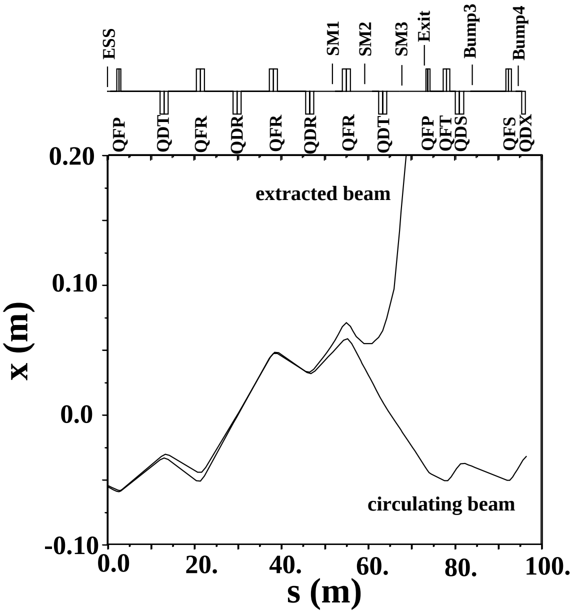

Figure 2: Orbit trace for the extracted and circulating particles.

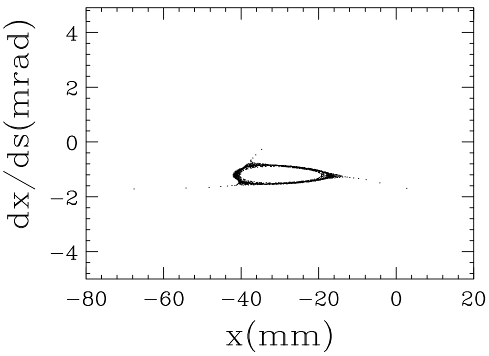

Figure 3: Single particle motions in x-x' phase space.

$\sim$20 mm for the ESS-gap length of 25 mm. Figure 3 shows the single particle motions in x-x' phase space at the ESS entrance. When we calculate beam-hit rate at the ESS wires, the ESS length is assumed to be 1.5 m and the wire thickness to be 0.1 mm. Minimum beam-hit rate can be found by changing the ESS angle. The angular spread of the extracted beam can be reduced by changing the bump orbit during extraction (dynamic bump) instead of fixed bump. Figure 4 shows the x-x' space distribution of the extracted beam at the ESS entrance for fixed and dynamic bump. The angular spread is drastically reduced by the dynamic bump. As a result, the beam hit-rate on the wires is decreased.

The beam-hit rates calculated by the tracking simulation are summarized in Table 2. When the multipole field is included in the Q- and D-magnets, the beam loss at the ESS wires is 1% for the dynamic bump case. The influence of the multipole fields in the magnets on the beam loss seems to be smaller than that of the four-fold symmetry lattice in the previous version[4].

4 ELECTROSTATIC SEPTUM

The electrostatic septum is one of the crucial hardware components for the slow extraction. The kick angle of the ESS is designed to be 0.2 mrad for the 50 GeV proton beam. The required electric field strength is 6.8 MV/m for the length of 1.5 m. The gap is chosen to be 25 mm to obtain the maximum step size of 20 mm for the extracted beam. The required cathod voltage is 170 kV. In order to achieve the goal, we have constructed an ESS model for R&D[5]. The feedthrough has a ceramics cylinder filled with Fluorinert as an insulating material. The septum wires of 80 μm in diameter arranged with a 1.25 mm spacing. The alignment error of the septum wires is designed to be within ± 10 μm. As a result, effective septum thickness is estimated to be 100 μm. The cathode material is stainless steel. The cathode length is 0.7 m which is about half length of the real one. In the high voltage test, we have achieved 182 kV over the design voltage for the gap of 25 mm. But discharge occurs regularly every a few minutes at the design voltage. We will need the conditioning at a

Table 1: Beam loss at the ESS wires

	beam-hit rate
no multipole field in Q and D mag.	
fixed bump	1.5%
dynamic bump	1.0%
multipole field in Q and D mag.	
fixed bump	2.5%
dynamic bump	1.0%

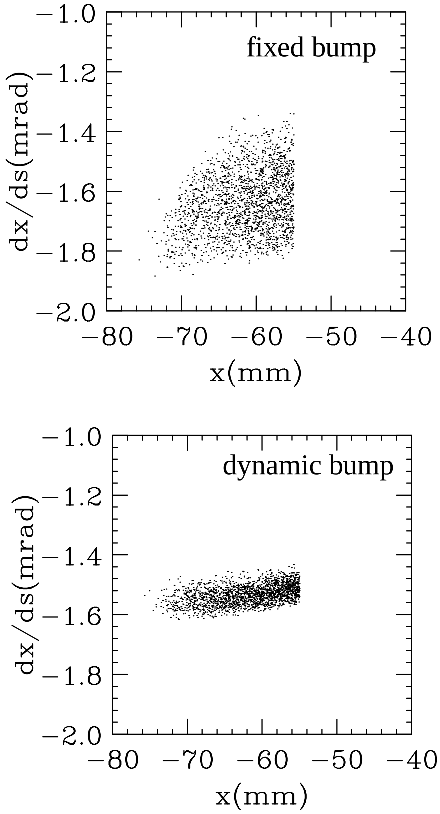

Figure 4: x-x' phase space distribution of the extracted beam at the ESS entrance for fixed and dynamic bump.

higher voltage to achieve more stable operation. We will also try to replace the stainless-steel electrode with oxidized aluminum. In the next step, we have a plan to use septum wires with diameter of 50 μm in order to decrease the beam loss.

Table 2: Parameters of the electrostatic septum

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

5 SEPTUM MAGNETS

Three type of magnetic septa (SM-1∼SM-3) are placed downstream from the ESS in the LSS. Each septa are divided into two or three pieces. Parameters of the SMs are listed in Table 3. If the extracted beam passes through air in the SMs, the MARS[6] simulation predicts that the beam loss due to it exceeds the criterion determined from the radiation safety. Therefore all SMs are housed in vacuum chambers. Magnetomotive force of the SM-3 is very large, since field strength of the SM-3 is 1.7 tesla. If the SM-3 is pulse-operated corresponding to the acceleration cycle, mechanical damage to the coil is serious. Therefore we have decided to operate the SM-3 at DC mode. This case, cooling of the septum coil is crucial part. The design of the SM-3 is now in progress.

Table 3: Parameters of magnetic septa

septum magnet	SM-1	SM-2	SM-3
number	2	3	3
$\theta_{\rm kick}$ (mrad)	+1.0	+3.0	+24
B (tesla)	0.11	0.34	1.7
length (m)	1.5	1.5	2.4
gap (mm)	38	40	42
NI (kA·turns)	3.43	10.8	57.1
$t_{\rm septum}$ (mm)	1.0	5.0	30.0
$J_{\rm septum}$ (A/mm^2)	89.9	54.1	45.1

6 CONCLUDING REMARKS

We have designed a scheme of the third-integer extraction from the 50-GeV ring of the JAERI/KEK Joint Project. The beam loss at the ESS wires was calculated by the tracking simulation. The simulation shows that the loss can be reduced up to 1% by changing the bump orbit during the extraction. we have constructed an R&D electrostatic septum and achieved the design voltage. The conditioning at higher voltage or replace of cathod material from the stainless-steel to oxidized aluminum are necessary in order to achieve more stable operation.

7 ACKNOWLEDGMENT

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8 REFERENCES

[1] Y. Yamazaki, "High-Intensity Proton Accelerators for the JAERI/KEK Joint Project", these proceedings.

[2] JHF Accelerator Design Report, KEK Report 97-16 (JHF-97-10),1998.

[3] N. Tokuda *et al.*,"Design Study of the Slow-Extraction System for the JHF 50-GeV Ring", Proc. of the First Asian Particle Accelerator Conf.,KEK Proc. 98-10, p.387.

[4] M. Tomizawa *et al.*,"Influence of Nonlinear Multipole Fields on Beam Loss in the Slow Extraction from JHF Main Ring", Proc. of 1998 the European Particle Accelerator Conf., p.2143.

[5] S. Shibuya *et al.*,"Development of an R&D Electrostatic septum for the 50-GeV Proton Synchrotron ", these proceedings.

[6] N. V. Mokhov, The MARS Code System Users Guide ,1998.