DESIGN OF SLOW EXTRACTION FROM 50-GeV PROTON SYNCHROTRON

M. Tomizawa*, Y. Arakaki,N. Tokuda and T. Yokoi
KEK, 1-1 Oho, Tsukuba, Ibaraki 305-0801, Japan

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 for a new lattice version 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%. Present status of septa design and a radiation study by MARS are also reported.

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 Nuclear and Particle Physics Facility (K-arena) by a slow extraction. The beam is debunched after acceleration, and is extracted over a period of 0.7 s for an acceleration cycle of 3.64 s. In a design of the slow extraction, beam loss must be less than 1% level, which is required from the radiation safety. A third-integer slow extraction has been adopted for the 50-GeV main ring. 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). To reduce it, the step size should be chosen to be as large as possible within the gap length of the ESS. The angular spread of the particles should be also small in order to reduce the beam loss at the ESS wires and the next septum. On the basis of these points, the slow extraction system has been designed. For a new lattice version, the beam loss at an electrostatic septum were examined by the tracking simulation. The radiation issues due to the beam loss at the ESS wires have been studied by MARS. Present status of the ESS and magnetic septa (SMs) is also reported.

2 SLOW EXTRACTION SCHEME

Characteristics of the 50-GeV 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 has 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. 8∼12 sextupole magnets placed in arc sections 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 = 39.0 m, and α_x = −0.001. The ESS wires are positioned so that x = −58 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 245.5 degree, which makes a separation of 3.6 mm between kicked and not kicked particles at the ESS. The arrangement of septa and bump magnets and beam envelopes in the LSS for the slow extraction are shown in Fig. 1.

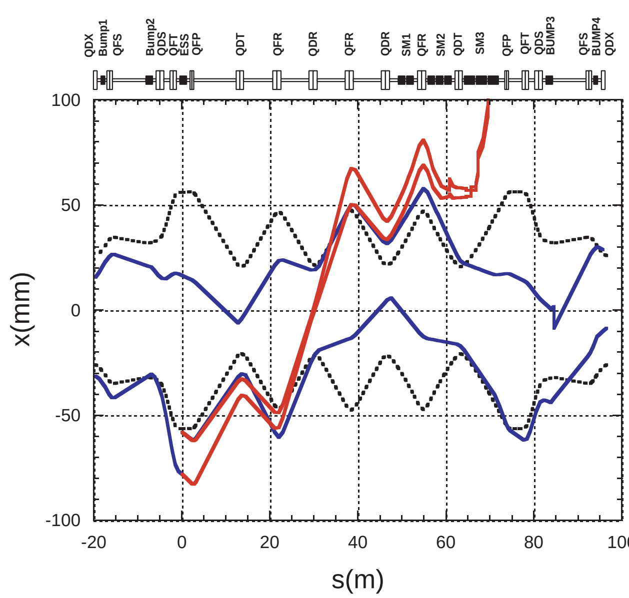

Figure 1: Layout of the LSS for the slow extraction and beam envelopes. Dotted line:injection beam, blue one:beam just before extraction, red one:beam kicked by the septa.

* masahito.tomizawa@kek.jp

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 $\pm$0.31%, in which 2000 particles are distributed. The resonant sextupole strength is chosen so as to be the step size less than $\sim$20 mm for the ESS-gap length of 25 mm. 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 as shown in Fig. 2. The angular spread of the extracted beam can be reduced by changing the bump orbit during extraction (dynamic bump) instead of fixed 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 1. When the multipole field is included in the Q- and D-magnets, the beam loss at the ESS wires is less than 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[2, 3, 4].

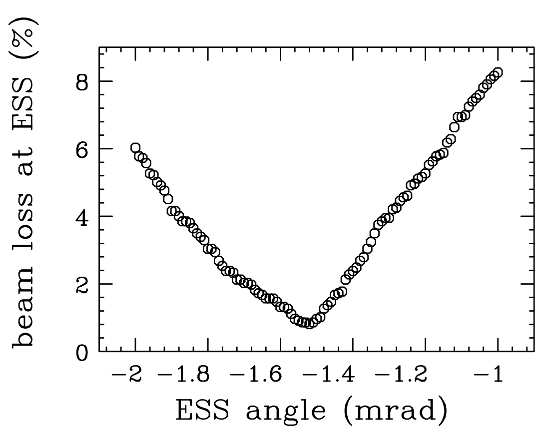

Figure 2: Beam hit rate as a function of the ESS angle.

4 ELECTROSTATIC SEPTUM

The electrostatic septum is one of the crucial hardware components for the slow extraction. Basic parameters of the ESS are listed in Table 2. 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 cathode 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 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 237 kV over the design voltage for the gap of 25 mm. At this voltage, the ceramics feedthrough (A479) was broken by discharge. A SEM examination for broken area suggests this trouble was caused by a stainless steel fragment sticked on the ceramics surface. A new ceramics feedthrough (KP-999) has been prepared. High voltage test will start soon. 50 μm wires can be available if wire frame to fix the wires is replaced from SUS to aluminum. If such thin wires are used, alignment errors of the wires are very important to reduce effective thickness. Alignment error of a test model has been measured by a laser focus displacement meter[6]. Measured alignment error was $\pm 15\mu$m. One less than $\pm 10\mu$m will be possible by a careful machining on the surface to determine the alignment.

Table 1: Beam loss at the ESS wires

	beam-hit rate
no multipole field in Q and D mag.	
fixed bump	1.3%
dynamic bump	0.56%
multipole field in Q and D mag.	
fixed bump	1.3%
dynamic bump	0.81%

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 MAGNETIC SEPTA

Four type of magnetic septa are placed downstream from the ESS in the LSS. Parameters of these SMs are listed in Table 3. The SM1 and SM2 are housed in vacuum chambers. On the other hand, the chambers are installed in the gaps for the SM3-1 and SM3-2 Magnetic field of the SM3-1 is rather mitigated comparing previous parameters[7]. A opposite field type is proposed for the SM3-1 [8]. Since a polarity of magnetic field in this magnet becomes reverse in the septum coil, electromagnetic force cancels for the septum coils. Therefore large aperture and pulse operation can be possible.

Table 3: Parameters of magnetic septa

septum magnet	SM1	SM2	SM3-1	SM3-2
number	2	3	1	2
$\theta_{\rm kick}$ (mrad)	$+1.0$	$+3.3$	$+18.3$	$+22.2$
B (tesla)	0.114	0.374	1.35	1.64
length (m)	1.5	1.5	2.3	2.3
V-gap (mm)	45	60	60	50
H-gap (mm)	60	60	110	110
$t_{\rm septum}$ (mm)	1.0	5.0	30.0	>30.0

6 RADIATION STUDY IN THE SLOW EXTRACTION

As mentioned above, though the beam hit rate on the ESS wires is suppressed to about 1%, it corresponds to huge beam loss power (7.5 kW). From the point of view of machine maintenance, some radiation issues due to beam loss at the ESS have been studied using MARS code[9]. 1200 wires of 1.5m long ESS are replaced by a thin bulk with corresponding density for modeling of the MARS.

6.1 Radiation Around ESS

The quadrupole magnet just downstream of the ESS is expected to suffer from the most serious radiation damage. Polymide resin which is extremely stable for radiation is used for coil insulation. The MARS result shows that absorption dose reaches 16 MGy/year in maximum assuming 5000 hours operation per a year. This case, the life time is estimated to be about 25 years, which is tolerable. The residual dose around the ESS was also estimated from the MARS. Assuming 30 day operation and 1 day cooling, residual dose reaches 150 mSv/h at the duct. But when titanium is used for the duct, it reduces roughly by factor 3. Though, these levels are similar to that of observed maximum one at the 12 GeV PS at KEK, in order to reduce exposure during maintenance works, we have a plan to adopt a remote connection-disconnection system for vacuum flanges we have developed.

6.2 Beam Loss of Scattered Protons Scattered by ESS Wires

The ESS wires are very thin, 80μm, such a case, most of incident protons are scattered out with small energy loss. In order to examine loss map in the ring of protons scattered by the wires, simulation study combining the result from MARS and tracking of scattered protons by SAD has been carried out. Preliminary results obtained from the simulation are as followed;(1) additional scrapers placed downstream of the ESS is useful to reduce a rate lost in the ring, especially at the next quadrupole magnet of the one just downstream of the ESS. (2) Every 3 turns, 20$\sim$30% of scattered protons is kicked out by the ESS. After 8 turns, no beam loss occurs in the ring. In next step, simulation study for scattered protons kicked by the ESS will be performed.

7 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 including the multipole fields in the Q- and D-magnets shows that the loss can be reduced to less than 1% by changing the bump orbit during the extraction. At an R&D electrostatic septum, we achieved the design voltage. After ceramics cylinder was broken by discharge, it was replaced a new one. High voltage test will start soon. From the point of view of machine maintenance, some radiation issues due to beam loss at the ESS have been studied using MARS code.

8 ACKNOWLEDGMENT

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