NON-LINEAR BEAM DYNAMICS DUE TO SEXTUPOLES IN PEFP RCS

Si-Won Jang, Eun-San Kim
Kyungpook National University, 1370 Sankyok-dong, Buk-ku, Daegu, 702-701, Korea

Abstract

Proton Engineering Frontier Project (PEFP) has a future plan for a 1 GeV RCS (Rapid Cycling Synchrotron) ring. In this paper, we investigated non-linear dynamics on third order resonance in sextupoles for slow beam extraction in the RCS. We investigated design of the slow beam extraction line and showed the results of the beam tracking in the beam line.

INTRODUCTION

Proton Engineering Frontier Project (PEFP) is a 100 MeV proton linear accelerator development project. The Rapid Cycling Synchrotron is a future accelerator for PEFP[1]. The basic parameters for the RCS are chosen to achieve the high current synchrotron. The 100 MeV proton beam is ramped to 1 GeV for the extraction at RCS. The number of proton per bunch is 2.5×10^{13} and the RCS has a four fold symmetry lattice. Several upgrade options are expected to increase the final proton energy and the beam current.

In this study, we investigated slow beam extraction system due to sextupoles in the RCS. Generally, slow beam extraction system is using the third order resonance. The main considerations to generate the third order resonance are strengths and locations of sextupoles. The size of the stable triangle region at the phase space depends on strength of sextupoles. For the stable beam extraction, we designed the slow beam extraction line at the RCS. The slow beam extraction line consists of four bump magnets, an electro static septum and five septum magnets. To slowly and continuously extract the proton beam in the RCS, we investigated the particle tracking simulations at phase space by using of MAD8 in detail.

EFFECTS OF THIRD ORDER RESONANCE IN THE RCS

The third order resonance at the RCS in PEFP is generated by betatron tune shift due to sextupoles (Fig. 1). For the 3rd order resonance, the equations of motion can be estimated by the following Hamiltonian [2]:

$$H = (\nu_x - m/3)J + RU_{3m}\cos 3\phi \quad \rightarrow \quad H = \delta J + \epsilon J^{3/2}\cos 3\phi,$$

where $\delta = \nu_x - m/3$ and $\epsilon = RU_{3m}/J^{3/2}$.

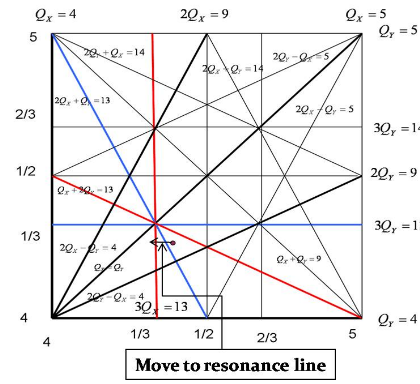

Figure 1: Slow extraction scheme due to changing the betatron tune.

Separatrix and tori of the third order resonance in the time independent Hamiltonian (Fig. 2) are plotted and the actions J_{SFP}, J_{UFP} are marked. Then we use m/3 = 13/3 and harmonic number = 1. Also, we use f_0 = 1.170 MHz. The contours in Fig.2 are plotted by using Hamiltonian in the J- ϕ space.

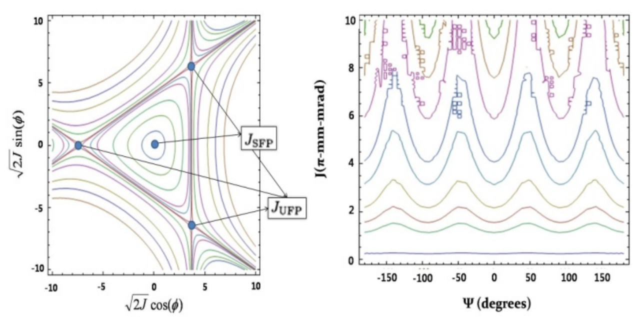

Figure 2: Betatron motion near the $3\nu_x$=13 resonance at the phase space in PEFP RCS.

DESIGN OF SLOW BEAM EXTRACTION LINE FOR THE RCS

Slow extraction line is located at long straight section. The line consists of 4 BM (bump magnet), 1 ESS (Electro Static Septum) and 5 SM (Septum Magnet). PEFP RCS has 2.5×10^{13} protons per pulse and 60 kW full beam power at 1 GeV. RCS circumference is 222.16 m with four fold symmetry period. Characteristics of this slow extraction line are as follows [3]:

- The long straight section of slow extraction line has 20.94 m.
- The bump magnets, ESS and septum magnets can be placed in this line.
- The long straight section has high β_x and low x section for ESS.
- The η and η' are zero in this line.

The horizontal betatron tunes ν_x is approached from upper of the resonance 13/3 to the resonance. The horizontal and vertical chromaticities are set to zero by 6 sextupole magnets in the C1, C2, and C3 position (Fig. 3). Four sextupole magnets are used to excite the resonance in the S2 position.

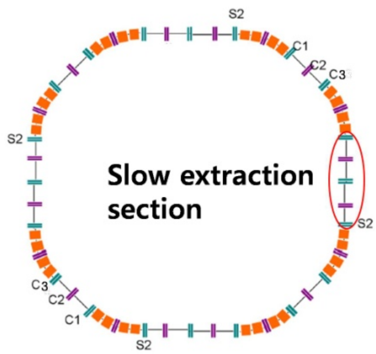

Figure 3: PEFP RCS layout. Slow extraction line exists in inner of red round line. Here S2 is locations of sextupoles for leading third order resonance. C1, C2, and C3 are locations of sextupoles for the chromaticity correction.

TWISS PARAMETER OF PEFP RCS

We investigated Twiss parameters of slow extraction line using MAD8 program [4]. Table 1 shows the tune and chromaticity at ESS due to existence and nonexistence of bump magnets. The shift in chromaticity due to the bump is very small.

Table 1: PEFP RCS Tunes and Chromaticities with and Without a Bump at the ESS.

Bump Amp(mm)	Q_x	Q_y	ξ_x	ξ_y
0	4.333	4.277	0.001965	0.30078
44	4.333	4.277	-0.42187	-0.13391

Table 2 shows Twiss parameters at ESS and each sextupole magnets. The electro static septum was placed at high β_x and low α_x position. Sextupole magnets for leading 3rd order resonance are placed at the last part of short straight section of each period.

Table 2: Twiss Parameters at ESS and Sextupoles.

Location name	β_x	μ_x	α_x	x	η_x
ESS	19.59	1.084	-2.029	42.227	-0.124
SFX21	16.98	0.153	-1.654	6.521	-.0552
SFX22	16.30	1.240	-1.600	0.978	-0.087
SFX22	16.06	2.323	-1.622	3.999	-0.311
SFX21	16.86	3.407	-1.702	6.066	-0.442

BEAM TRACKING IN THE DESIGNED SLOW BEAM EXTRACTION

Four bump magnets are placed slow extraction section. These four bump magnets shift the closed orbit outwards by 44 mm. ESS was placed 42 mm to x-direction. Table 3 shows the bump magnets and ESS parameters used in the MAD8 program [4] for slow beam extraction simulation.

Table 3: Parameters of Bump Magnets and ESS in the MAD8.

Magnets	Type	Length	Value
BUMP1	KICKER	0.5 m	0.023 rad
BUMP2	KICKER	0.5 m	-0.023 rad
BUMP3	KICKER	0.5 m	-0.023 rad
BUMP4	KICKER	0.5 m	0.023 rad
ESS	ELSEPARATOR	0.5 m	0.715 MeV/m

Using Table 3 parameters, we performed single particle tracking simulations at the RCS. Single particle tracking simulations depend on pole sign of sextupole magnets. Figure 4 shows results of the simulations due to combinations of different signs of sextupole magnets.

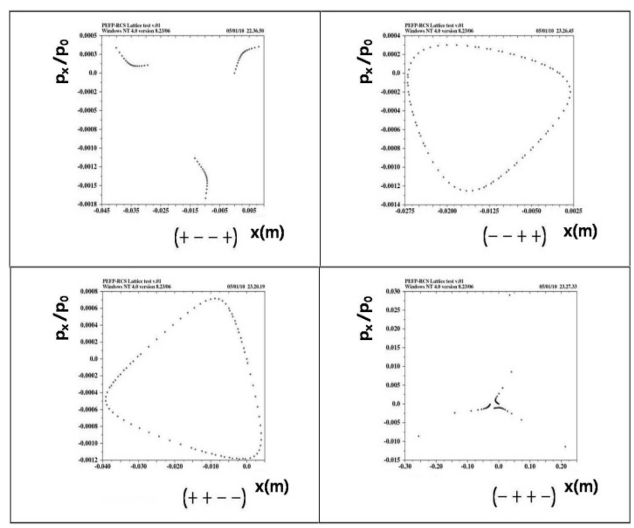

Figure 4: Results of single particle trackings due to the different poles of sextupole magnets.

In these four conditions, we selected (+,-,-,+) sign order for the slow beam extraction. The ESS was installed at x = 42 mm. The initial conditions of the single particle tracking simulation at ESS are x = 1.45 mm, px = -0.65 mrad and the momentum spread is 0.3 %. Figure 5 shows the single particle motion in x-p_x phase space at ESS entrance. The ESS length is assumed to be 0.5 m and strength is assumed 0.715 MeV/m. The result of tracking simulation shows that the particle moves along the separatrix branch. When the particles is moving up to 42 mm and then the particle will be extracted to external beam line by ESS.

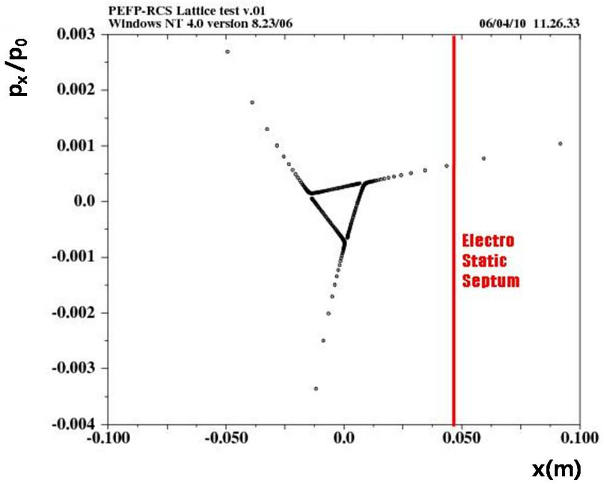

Figure 5: Single particle motion through tracking simulation in x-p_x phase space.

The orbit for the slow extraction was shifted up to 44 mm due to bump magnets and then separated beam at ESS is extracted along external beam line by septum magnets. For the PEFP RCS, two types of septum magnets are placed downstream from the ESS in the slow extraction line [5]. Figure 6 shows the scheme of the designed slow beam extraction line.

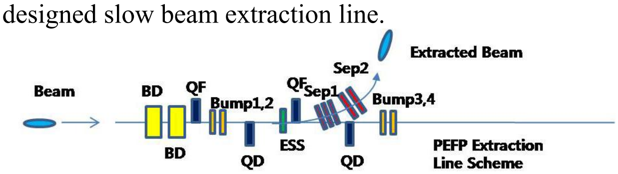

Figure 6: Scheme of the slow beam extraction line at the RCS.

The first type of septum magnets is set to 0.5 m length and 0.2 rad angle. The second type of septum magnets is set to 1 m length and 0.5 rad angle. Also, we performed beam orbit tracking simulations due to the septum magnets at the slow beam extraction line. The separated beam by ESS leaves out the ring vacuum chamber due to septum magnets. Figure 7 shows the results of the beam orbit tracking of the extracted particles at ESS.

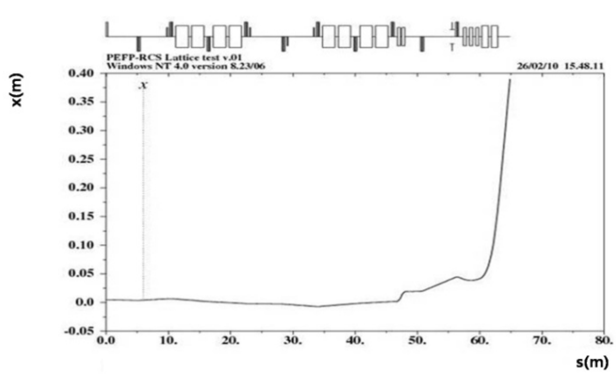

Figure 7: The beam orbit of the extracted particles at the RCS in PEFP.

SUMMARY

We investigated the non-linear beam dynamics due to sextupole magnets at the RCS in PEFP. Effects of the third order resonance are examined and the slow extraction system due to sextupoles was investigated. The slow extraction from the RCS makes use of a sextupole magnets that drive the third order resonance controlled by tune ramping. The single particle tracking simulation was performed to observe the motion of single particle at the phase space. The beam orbit tracking simulation at the RCS shows that the beam paths of the extracted particles are stable. Through the results of simulations and calculations, it is shown that we optimized a slow extraction system and achieved optimal parameters for the RCS.

REFFERENCES

[1] B. Chung, Y. S. Cho and Y. Y. Lee, Conceptual Design of the PEFP Rapid Cycling Synchrotron: Proceedings of PAC07 (Albuquerque, NM, 2007), p. 2817.

[2] S. Y. Lee, Accelerator physics (World Scientific, Singapore, 2004), p. 220.

[3] M. Tomizawa, Y. Arakaki, N. Tokuda and T. Yokoi, DESIGN OF SLOWEXTRACTION FROM 50-GeV PROTON SYNCHROTRON: Proceedings of EPAC 2002 (Paris, France, 2002), p. 1058.

[4] H. Grote and F.C. Iselin, The MAD Program, Version 8.16, User's Reference Manual, CERN SL/90-13 (AP) Rev. 4 (1995).

[5] A. Noda, T. Sugimura, T. Shirai, Y. Iwashita, A. Morita, H. Fujita and H. Tongu, Slow Extraction of Electron Beam with Combination of the Third Order Resonance and RFKO: Proceedings of PAC2001 (Chicago, 2001), p. 3591.