STUDY OF INFLUENCE OF DIPOLE AND QUADRUPOLE POWER RIPPLE ON SLOW EXTRACTION FOR XiPAF

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Abstract

The third resonant slow extraction and RF-Knockout technology was adopted for XiPAF, which was designed for proton single event effects. The separatrix of the stable region fluctuates during slow extraction due to power ripple, which affects the extracted beam uniformity and the extraction efficiency. The influence of dipole and quadrupole power ripple was explored theoretically and simulated via MPI parallel multi-particle program. A method for making the beam less sensitive to power ripple is proposed and verified by simulation.

INTRODUCTION

The Xi'an Proton Application Facility (XiPAF) is currently under construction for research on the single event effect (SEE). It consists of a 7 MeV linac injector, a synchrotron (60~230MeV) and two experimental stations [1]. The parameters of XiPAF related to extraction are shown in Table 1. To satisfy the requirements of the SEE experiments, the RF-KO slow extraction method should be adopted to obtain a unformed spill. Power supply ripple, however, cause the extracted spill to fluctuate.

This paper introduces the C++ code Li-Tracker, which can be used to simulate the third order slow extraction process. The influence of the quadrupoles/dipoles on extracted spill was investigated in this study by computer simulation, as discussed below.

Table 1: XiPAF Synchrotron Parameters

Parameter	Value	Unit
Injection Energy	7	MeV
Extraction Energy	60~230	MeV
Circumference	30.9	m
Maximum Repetition Rate	0.5	Hz
Maximum β_x/β_y	5.8/6.0	
Extraction Time	1~10	s
Extraction υ_x/υ_y	1.678/1.794	

LI-TRACK CODE FOR EXTRACTION

The Li-Track code is a parallel multi-particle tracking program based on MPI. It consists of the total of XiPAF components. The initial coordinates of particles form the input of the program; if the lattice in the program is al-

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tered, it can be used for other accelerators as well. Figure 1 shows the simulation result of an extracted spill in Li-Track code. The dual FM method [2] and AM function [3] were applied to make the extracted spill more uniform. The related parameters are listed in Table 2.

Table 2: Simulation Parameters

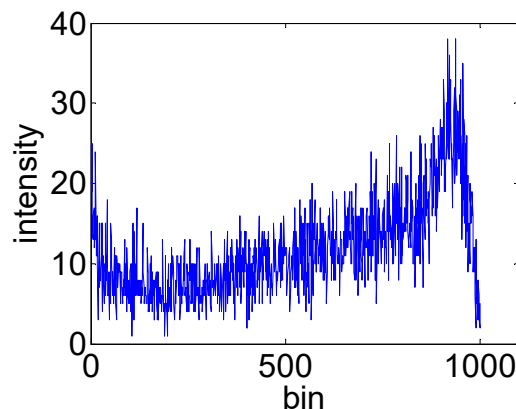| Parameter	Value	Unit
Extraction Energy	60~230	MeV
Revolution Frequency	5.78	MHz
Center Frequency	3.92	MHz
Bandwidth	37	kHz
AM Parameter r_0^2	34.4×10^{-6}	
AM Parameter σ_0^2	4.4×10^{-6}	
Extraction υ_x/υ_y	1.678/1.794	
τ_{prac}/τ_{ext}	1.2	

Figure 1: Extraction spill structure (extracted particles recorded every 5780 turns corresponding to 1 KHz sampling frequency).

In this simulation, 1.2×10^4 particles were tracked for 5.78×10^6 turns (equivalent to 1 s). Eleven hours were needed to complete the simulation using 120 CPU.

EFFECT OF QUADRUPOLLE MAGNET

The stable area of the third order resonance is propotional to δQ^2, where

$$\delta Q = Q_{particle} - Q_{resnonce}$$

The lattice tune is mainly determined by the quadrupoles. Ripple in the quadrupole power leads to disturb-

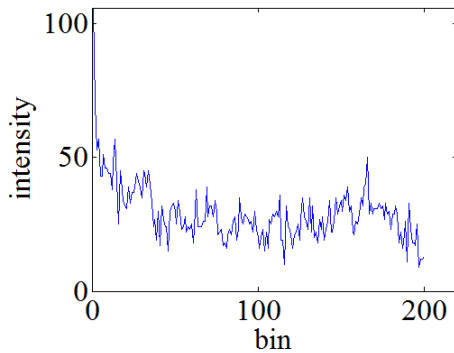ance, which then changes the stable area of the resonance and causes a modulation in the extracted spill.

Consider a thin-lens quadrupole with field errors k(s) and the integrated strength of field error $\int \Delta K_1 ds = \Delta K_1 L$, where L is the length of quadruples. The tune shift due to the power ripple of quadrupoles can be expressed as follows:

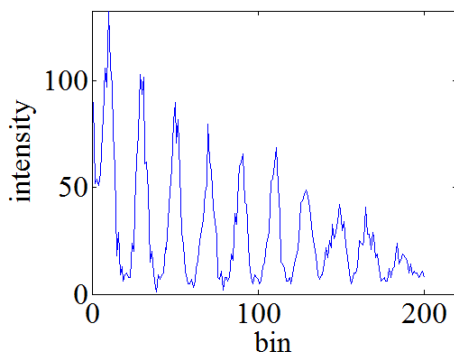$$\Delta v = \frac{L\beta}{4\pi} \Delta K_1$$

(a)
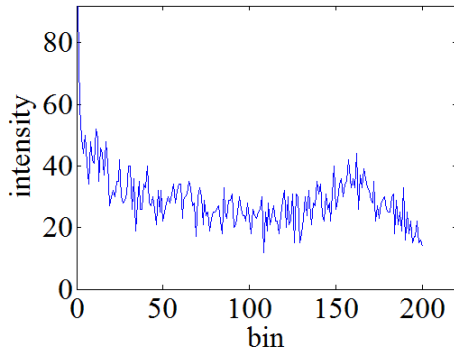
(b)

(c)

Figure 2: Simulation results with QF ripple: (a) no ripple; (b) $\frac{\Delta I}{I} = 60$ppm; (c) $\frac{\Delta I}{I} = 500$ppm.

For the Focusing Quadrupole (QF), L = 0.24m, β = 5.8m, and the XiPAF consists of 6 QFs, so the tune shift due to the QF can be calculated as follows:

$$\Delta v = 6 \times \frac{0.24 \times 5.8}{4\pi} \Delta K_1 = 0.67 \Delta K_1$$

$$\frac{\Delta I}{I} = \frac{\Delta B}{B} = \frac{\Delta K_1}{K_1}, \text{ so}$$

$$\Delta v = 0.67 \Delta K_1 = 0.67 K_1 \frac{\Delta I}{I_{set}} = 1.57 \frac{\Delta I}{I_{set}}$$

The relation between the power ripple of Defocusing Quadrupoles and tune shift can be obtained similarly:

$$\Delta v = -0.15 \frac{\Delta I}{I_{set}}$$

Extraction with power ripple was simulated to determine the limitation for the power ripple, which was assumed to be a sinusoidal function. Figure 2 shows the QF simulation result; Figure 3 shows the result for QD. The ripple frequency was set to 50 Hz.
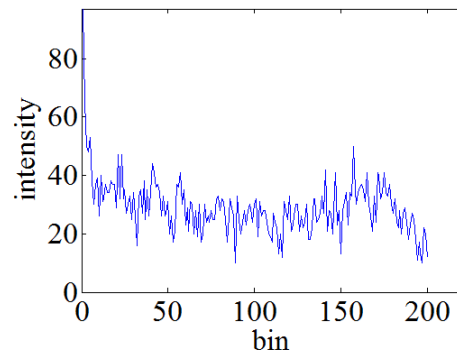
(a)
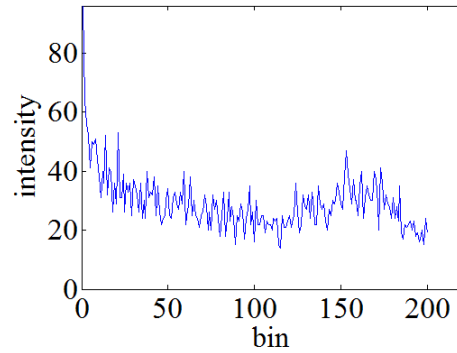
(b)

Figure 3: Simulation results with QD ripple: (a) $\frac{\Delta I}{I} = 60$ppm; (b) $\frac{\Delta I}{I} = 500$ppm.

The simulation results indicate that when $\frac{\Delta I}{I} = 60ppm$ for QF, the extracted spill time structure is similar to that with no ripple. In other words, $\frac{\Delta I}{I} = 60ppm$ is tolerable for QF. The tolerable ripple of QD can be up to 500 ppm, because the tune is much less sensitive to the ripple of QF.

INFLUENCE OF DIPOLE MAGNET

The influence of dipole power converter ripple on extraction can be analyzed from two perspectives: The closed orbit and the particle's tune.

The influence on the closed orbit can be calculated as follows:

$$u(s) = \theta \frac{\sqrt{\beta_0 \beta_s}}{2 \sin \pi \nu} \cos(\pi \nu - |\varphi(s) - \varphi(s_0)|)$$

If $\frac{\Delta I}{I}$ for the dipole power converter reaches to 100 ppm, the fluctuation of the closed orbit at the entrance of the electrostatic septum is 0.225 mm. Compared to the spiral step (5 mm), the fluctuation can be negligible.

The influence of dipole magnet ripple on the tune merits further research.

MAKING BEAM LESS SENSITIVE TO POWER RIPPLE
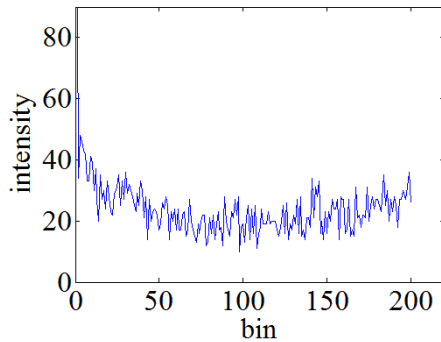
The area of the stable region can be expressed as follows:

$$A = \frac{48\sqrt{3}\pi}{S^2}(\delta Q)^2 \pi$$

Assuming that the tune shift resulting from the power converter ripple is dQ, the area changes to:

$$\frac{\Delta A}{A} = \frac{(\delta Q + dQ)^2 - \delta Q^2}{\delta Q^2} = 2\frac{dQ}{\delta Q}$$

A large difference between tune and resonance is beneficial to making the extracted spill less sensitive to power supply ripple.

(a)   no ripple

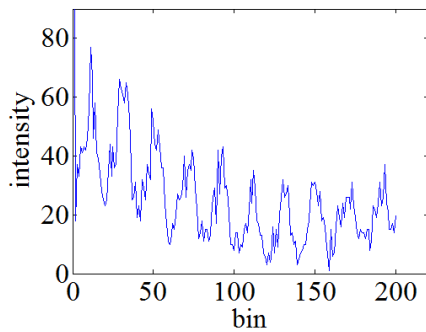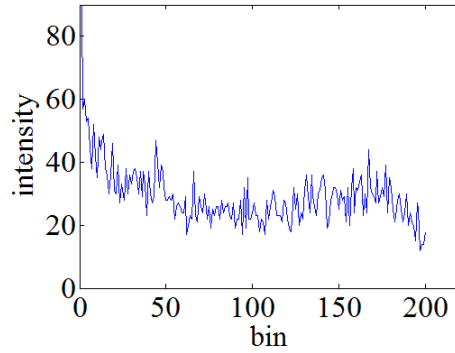(b) $\frac{\Delta I}{I} = 60 ppm$

Figure 4: Simulation result for tune = 1.669.

(a)   no ripple

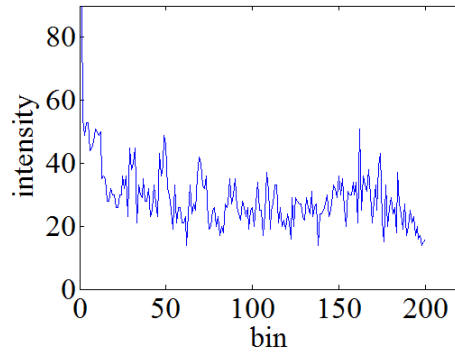(b) $\frac{\Delta I}{I} = 60 ppm$

Figure 5: Simulation result for tune = 1.690.

Figures 4 and 5 show the simulation result for tune = 1.669 and 1.690. The stable area was kept constant in the simulation so the normalized sextupole strength could be altered accordingly.

The results indicate that modulation caused by tune fluctuation was more severe at tune = 1.669 than at tune = 1.690. However, a larger difference between tune and resonance means a stronger sextupole so as to make the stable region constant. The nonlinear effect due to the higher strength of sextupole must to be taken into account.

CONCLUSION

This paper introduced a parallel, multi-particle tracking program. The relationship between the tune shift and ripple of power converters was given quantitatively. According to a series of simulation results, $\frac{\Delta I}{I} = 60 ppm$ for the QF power converter and $\frac{\Delta I}{I} = 500 ppm$ for the QD converter are acceptable. Comparison between tune = 1.669 and 1.690 further indicated that greater distance from the resonance makes the extracted beam less sensitive to power supply ripple.

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