TRANSVERSE RF KICKER EXCITATION AND LONGITUDINAL RF NOISE DIFFUSION FOR SLOW EXTRACTION FROM SAPT

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Abstract

The sipll quality of extracted beam from medical synchrotron is crucial to cancer treatment in particle therapy. Two key techniques used in the slow extraction from synchrotron accelerator, namely transverse RF kicker excitation and longitudinal RF noise diffusion, are examined here. For the transverse RF kicker excitation, signals with monofrequency and finite bandwidth have been used in simulations to excite the particles, and results show the different velocities of dQ/dt related to the frequencies, initial phases, and strength of the corresponding signals. The longitudinal RF noise diffusion technique is also tested here to show its pontential to be used as a substitute slow extraction method.

INTRODUCTION

Shanghai Advanced Proton Therapy (SAPT) which is currently under construction consists of a 7MeV injector, a 7-250 MeV synchrotron, beam transfer lines, 3 gantry treatment rooms, 2 fixed treatment rooms. The number of extracted particles is 4-8×10^{10} per spill, which can meet the requirement of 2 Gy/minute in most of target areas. The synchrotron has a maximal repetition period of 1.5 seconds.

The quality of the slow extracted beam from synchrotron, namely the uniformity and duty factor, is essential to an effective medical treatment. Resonance slow extraction itself is sensitive to disturbance, particularly the power ripples, which can be transformed into the tune ripples through magnetic field. Particles near resonance are high sensitive to the tune fluctuation which will be amplified into the spill ripples when extraction. There are several ways to enhance the quality of extracted beam and to suppress the ripples in the spill. One way is to lower the ripples in the power supply. From simple estimation, we conclude that power ripples have to be maintained to a demanding level of around 1×10^{-6} . The other way is to improve the scheme of slow extraction.

In this paper, we investigate how the strength, frequency, initial phase of different kind of RF kicker signals such as monofrequency sine wave and colored noise with a center frequency and finite bandwidth affect the particle velocity dQ/dt to cross stability limit. And global uniformity can be achieved by feedforward AM function which relate kicker amplitudes to time of spill, so as to keep the spill rate constant. The longitudinal RF noise diffusion technique is also tested here to show its pontential to be used as a substitute slow extraction method.

SIMULATIONS OF TRANSVERSE RF KICKER EXCITATION

The extraction energy ranges from 70-250 MeV, but in this paper only the highest energy is treated. Basic parameters which are related to the simulations are listed in table 1.

Table 1: Parameters of Ring and Input for Simulations

Energy	250 MeV
Horizontal tune	1.67
Horizontal chromaticity	-0.58
Revolution frequency	7.4779 MHz
Momentum deviation	0.002
Particle distribution	Uniform distribution
x	[-0.002,0.002]
xp	[-0.002,0.002]
Particles number	1000
Tracking turns	500

Monofrequency Sine Wave Excitation

Monofrequency sine wave $E_{kick}=A\sin(2\pi f_{rfk}t+\Pi_0)$ is applied to the RF kicker to excite the beam in the simulations. Here A's is the amplitude, f_{rev} and f_{rfk} the revolution and exciting frequencies, respectively, Π_0 is the initial phase.

Simulations with different exciting frequencies, initial phase, and strength are carried out. When the exciting frequencies are examined, the initial phases are set to zero, and the strength is 150 μrad; when strength is examined, the frequency is set to 5/3, and the initial phases are set to zero. The scenario is listed in table 2.

Table 2: Different Exciting Scenario in Simulations

frequency(Hz)	$5/3f_{rev}$	$4/3f_{rev}$	$1.67f_{rev}$	
strength(μrad)	100	150	180	200

The exciting frequency simulations (Fig.1-4) show, (a) exciting frequencies which differ by an integer have the same effect; (b) exciting tune 5/3 can effectively excite particles to enter resonance; (c) when using exciting tune 1.67, all the particles are extracted, but in two time sections which are separated, and the extracted particle angles are quite divergent; (d) exciting tune 4/3 is the most difficult to extract particles.

The exciting strength simulations (Fig.1-2,5-6) show, the stronger the exciting, the more and faster the extracted particles. When the particle number reaches the peak, it will decline exponentially. There is a time constant for the decline, the stronger the exciting, the shorter the time constant. We can calculate the time constants for different exciting amplitudes, and get a feedforward AM function which is used to sustain a spill of global uniformity.

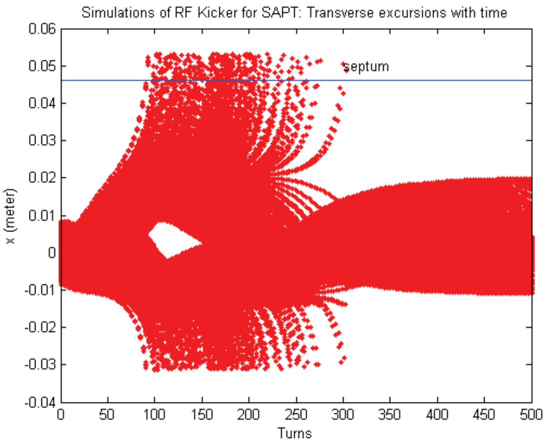

Figure 1: Particle displacement x vs. turn ($f_{rfk}=5/3f_{rev}$, $A=150,\phi=0$).

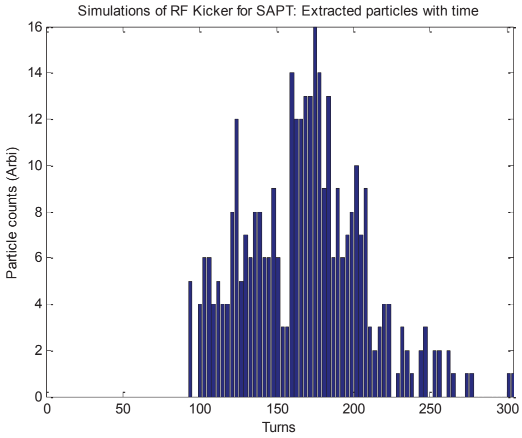

Figure 2: Particle number vs. turn ($f_{rfk}=5/3f_{rev}$, $A=150,\phi=0$).

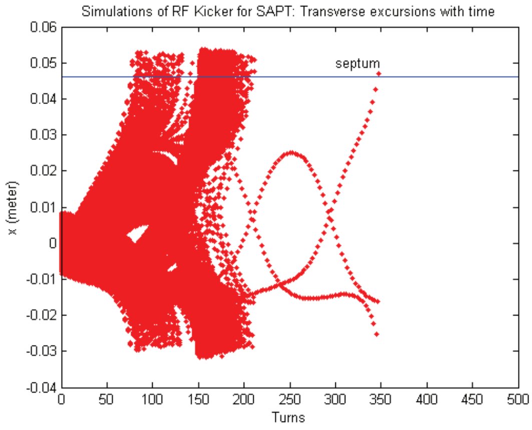

Figure 3: Particle displacement x vs. turn ($f_{rfk}=1.67f_{rev}$, $A=150,\phi=0$).

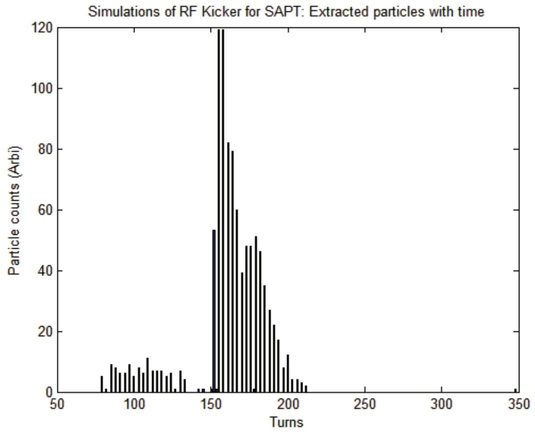

Figure 4: Particle number vs. turn ($f_{rfk}=1.67f_{rev}$, $A=150,\phi=0$).

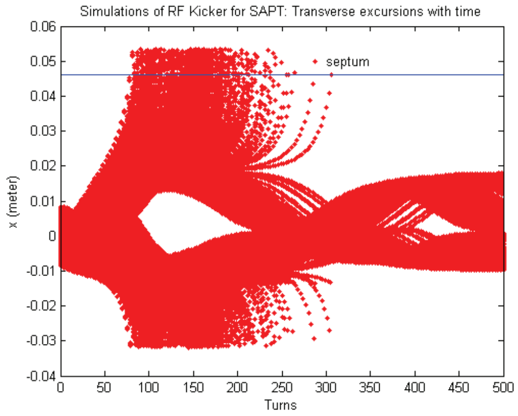

Figure 5: Particle displacement x vs. turn ($f_{rfk}=5/3f_{rev}$, $A=180,\phi=0$).

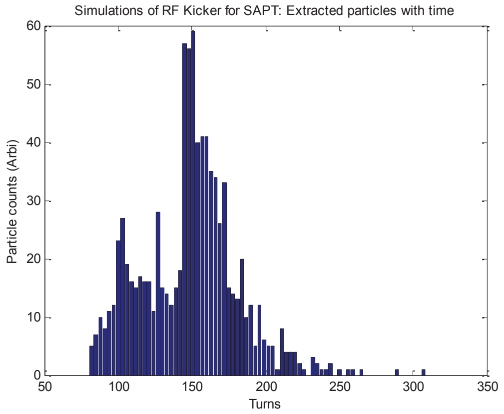

Figure 6: Particle number vs. turn ($f_{rfk}=5/3f_{rev}$, $A=180,\phi=0$).

Synthetic "Colored" Noise Exciting

Because the ring chromaticity is not zero, and the particles have momentum deviation, this means that tunes have a distribution. If the RF kicker exciting has a bandwidth which covers the tune distribution, it will be easy to extract the particles. A simple synthetic "colored" noise with a RMS amplitude A_{rms}=130 μrad is used here. There are four the frequency components which are

1.65,1.66,1.667, and 1.672. All of them are deviated from resonance tune 5/3 and work point tune 1.67.

Appling the "colored" noise to the RF kicker, the other simulation conditions are the same as above. The results are shown in Fig. 7-9. The particles have a large range of extracted angles. The time profile has four or five sections in which the particles are concentrated. It is clear the sections correspond to the four exciting frequencies, and two of them are dominant.

The extraction time profile of the synthetic "colored" noise is related to its frequency components. An ideal extraction effect can be achieved by careful tuning of the amplitudes, frequencies, and initial phases finely. There exists a problem that the particles have a large range of extracted angles, which means parts of the particles may hit the septum and are lost.

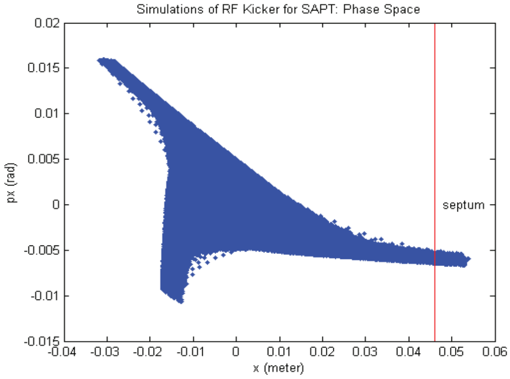

Figure 7: Phase space map of "colored" noise exciting.

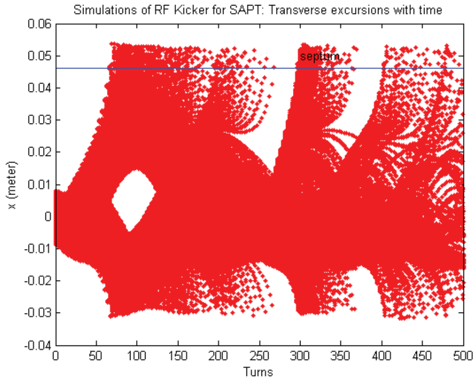

Figure 8: Particle displacement x vs. turn ("colored" noise exciting).

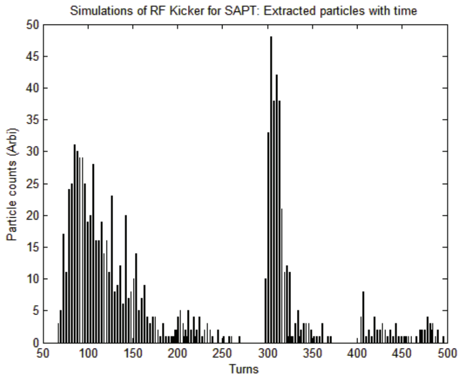

Figure 9: Particle number vs. turn("colored" noise exciting).

LONGITUDINAL RF NOISE DIFFUSION

According to S. van der Meer, a longitudinal RF noise with certain spectrum can be used to act on the coasting beam, which changes particle distribution in Q space, and causes the density low at the stability limit, and at the same time increases dQ/dt which leads to a low ripple extraction with improved uniformity.

Tracking is done by MAD PTC module. Given the initial coordinates x=[-0.0008, 0.001,0.0012], xp=[-0.0008, 0.001,0.0012]. When neither a transverse RF kicker nor longitudinal RF noise used as an exciter, the particles will travel in the phase space stably.

Longitudinal RF noise is generated by random number gehirator, dp/p=0.003*ranf()+0.002, and the result is shown in Fig. 10. We can see that the particles have been excited into resonance.

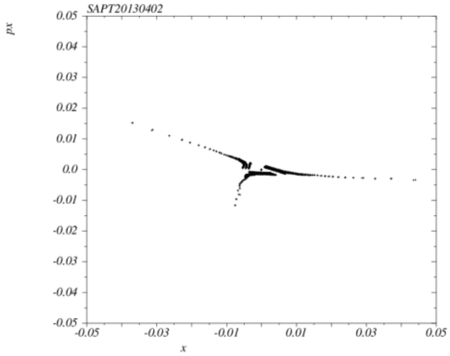

Figure 10: Phase space map longitudinal RF noise diffusion.

CONCLUSION

Two key techniques used in the slow extraction from synchrotron accelerator, namely transverse RF kicker excitation and longitudinal RF noise diffusion, are examined in this paper. Investigation is carried out to show how the strength, frequency, initial phase of different kind of RF kicker signals such as monofrequency sine wave and colored noise with a center frequency and finite bandwidth affect the particle velocity dQ/dt to cross stability limit. The longitudinal RF noise diffusion technique is also tested here to show its pontential to be used as a substitute slow extraction method.

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