SIMULATION OF MAGNET FIELD DISTURBANCE EFFECT ON THE THIRD ORDER RESONANT EXTRACTION

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Abstract

The third order resonant slow extraction experimental research has progressed at the main ring of HIRFL, but the extracted beam spill intensity is significantly modulated by some periodic disturbances which leaded to large-scale beam break during continuous extraction and hardly decreased beam emittance at external targets. The periodic beam disturbance can be attributed to the main magnet field disturbances by low-frequency ripple of magnet power supplies. The disturbance effect of quadruple and dipole magnetic fields on the extracted beam spill intensity variation and emittance are evaluated by simulation in this paper. The simulation result shows that the current quadruple field disturbance level has a strong impact on both beam spill intensity and extracted beam emittance on the main ring.

INTRODUCTION

Slow extraction of ion beam from synchrotrons are extensively applied in counter experiments of particle and nuclear physics at external targets and recently extends to radiation therapy application warmly in China after a series of striking therapy effect being achieved in deep tumour treatment at CSRm - the main ring of cooler storage rings of HIRFL. Although the RF-knockout assisted slow extraction technology have been successfully applied to CSRm [1] and an feedback system has been test to reduce the disadvantage effect by magnet field disturbance [2,3], but the simulation of magnet field disturbances effect on the resonant slow extraction are still under study.

It has been experimentally observed that the extracted beam spill intensity variation has some obviously periodic discontinuity and regular modulation features by some disturbances. This effect results in large-scale beam break during continuous extraction and hardly decreased extracted beam emittance on experimental external targets. The disturbances are attributed to higher magnetic field oscillation components by low-frequency ripples of the dipole and quadruple power supplies.

By analyzing the frequency spectrum of output current of dipole and quadruple power supplies, it shows that the higher amplitude ripples of these power supplies are typically located at 50 Hz and its integerharmonics below 1000 Hz. Due to the eddy effect, however, only the magnet field disturbances below 500 Hz should be considered in simulation. Figure 1 gives the extracted beam spill intensity variation both in time domain and frequency domain in experiments with "count/particle" and "amplitude" mean relative ion beam intensity [2,3].

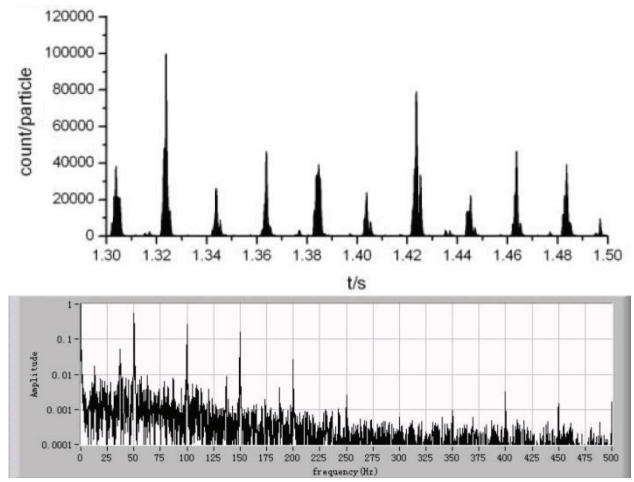

Figure 1: Extracted beam spill intensity variation in time domain and frequency domain [2,3].

EVALUATION THE EFFECT OF MAGNET FIELD DISTURBANCE

Distance of Working Point in Extraction from the Third Order Resonance

The CSRm horizontal bare working point is usually set to 3.663 in the third resonance slow extraction operation. Considering other contributions like tune change by space charge effect of stored ion beam and cooling electron beam and tune shift by nonzero chromaticity, the actual horizontal working point at the beginning of extraction usually locates at about $3.9\cdot10^{-3}$ below the third-order extraction resonance 11/3.

Stable Area under Magnets Field Disturbances

Considering the 30 quadruples powered independently have the same order of disturbance $1\cdot10^{-4}$, and the 16 dipoles series connected have $2\cdot10^{-5}$ disturbance. Simulation shows that $3.9\cdot10^{-4}$ and $2\cdot10^{-5}$ oscillation of horizontal working point would be induced by the quadruple field disturbance and dipole field disturbance respectively. Effect of sextuple field disturbance on the extraction can usually be ignored.

The stabilization area in phase space or the maximal allowed horizontal beam emittance in the third order resonance extraction is affected by the magnetic field disturbance and working point oscillation through:

$$\delta\varepsilon_{x\_stb} \approx 2\varepsilon_{x\_stb}\left(\left|\frac{\delta q_x}{\Delta q_x}\right| + \left|\frac{\delta S_{virt}}{S_{virt}}\right|\right) \tag{1}$$

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in which the maximal allowed horizontal emittance $\varepsilon_{x\_stb}=48\sqrt{3}\pi\Delta q_x^2/S_{virt}^2$, the horizontal working point oscillation amplitude $\delta q_x\approx3.9\cdot10^{-4}$, the horizontal working point distance from resonance in extraction $\Delta q_x=-3.9\cdot10^{-3}$, the sextuple field disturbance amplitude $\delta S_{virt}/S_{virt}\approx1\cdot10^{-4}$. According these calculations, the current CSRm magnet filed disturbance can induce the relative perturbation change about 20% of the stable area. Therefore, $1\cdot10^{-4}$ quadruple magnetic field disturbance can cause extracted beam spill intensity oscillation dramatically through perturbing stable area. The stable area perturbation can be decreased to 2.6% when the quadruple magnetic field disturbance is reduced to $1\cdot10^{-5}$. The effect of dipole and sextuple magnetic field disturbances on the stable area change can be ignored here.

Beside the disturbance, according to the calculation above the ion number change of stored beam also causes working point change throughout the extraction, i.e. $5\cdot10^9$ ion number variation can change the stable area by 20% when the synchrotron lattices keeps constant.

Spiral Step under Magnets Field Disturbances

Magnet field disturbance also changes the spiral step of extracted beam spill. Spiral step is equivalent to the maximum extraction spill width in real phase right before entering the first extraction electrostatic septum. Calculation shows that the spiral step change by the $2\cdot10^{-5}$ dipole field disturbance is 0.3 mm, and step change by the $1\cdot10^{-4}$ quadruple field disturbance is 0.05 mm.

SIMULATIONS

The RF-Knockout resonant extraction simulations are done by tracking 2000 sample ions under 500 Hz quadruple and dipole field disturbances at CSRm. The RF exciter starts to work at the 100^{th} revolution in simulation. Throughout the extraction, the RF exciter amplitude is kept with a constant kicker 1μrad and the central frequency is 0.664 times of revolution frequency. The exciter sweeps frequency band by saw-tooth waveform, and the sweeping bandwidth is 0.001 relative to the exciter central frequency. This bandwidth is about three times of oscillation amplitude of the horizontal working point. The sweeping period is 1ms or 1057 revolutions for 200 MeV/u carbon ions. The starting horizontal and vertical beam RMS emittance are 10 πmmmrad and 5 πmmmrad respectively. The spill intensities at the entrance of the first electrostatic septum vary with revolution turns are given by the histogram with the interval of 100 revolutions for 500 Hz magnet field disturbances.

Quadruple Magnetic Field Disturbance Effect

For $1\cdot10^{-4}$ quadruple field disturbance at 500 Hz, the extracted spill intensity variation is shown in Fig. 2(a), and the extracted beam spill distribution in phase space is shown in Fig. 2(b). For $1\cdot10^{-5}$ quadruple disturbances at 500 Hz, the extracted spill intensity variation and extracted beam spill phase space distribution are shown in Fig. 3. The horizontal axis label "turn" denotes revolution turns and the first vertical label "npart" denotes the number of extracted ions. The green line in these figures means the extraction efficiency which is defined as ion numbers ratio of the extracted to starting tracked at total.

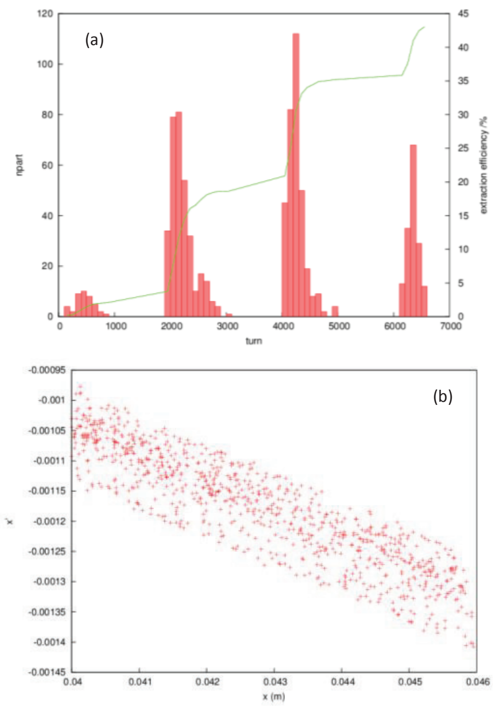

Figure 2: Extracted beam spill intensity vs. revolution turn (a) and distribution in horizontal phase space (b) under $1\cdot10^{-4}$ quadruple field disturbances.

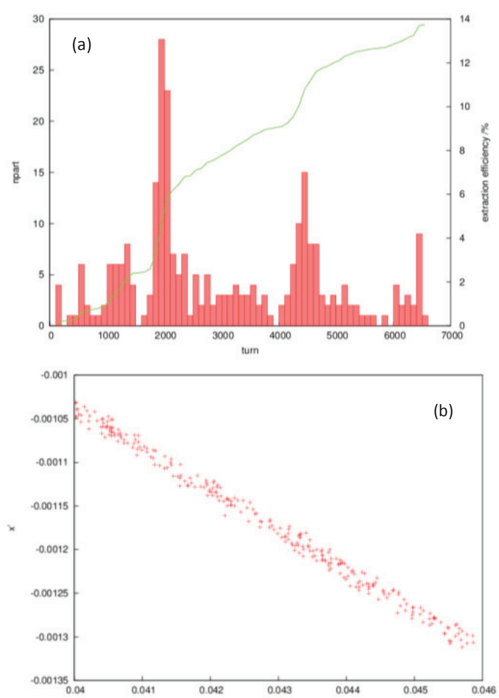

Figure 3: Extracted spill intensity vs. revolution turn (a) and distribution in horizontal phase space (b) under $1\cdot10^{-5}$ quadruple field disturbances.

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Simulation shows that $1 \cdot 10^{-4}$ quadruple magnetic field disturbance can obviously induce intensity modulation of extracted spill and increase the extracted beam emittance or beam width by eight times on external targets, while $1 \cdot 10^{-5}$ disturbance brings much less disadvantage effect to either extracted spill intensity or emittance. Figure 4 gives the impact of quadruple disturbance amplitude on extracted beam horizontal emittance. Therefore, less than $1 \cdot 10^{-5}$ quadruple field disturbance is required for approaching constant extraction and delicate experimental application.

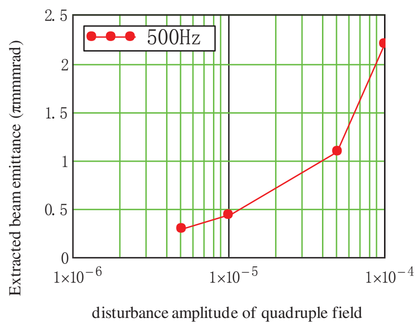

Figure 4: Extracted beam horizontal emittance vs. quadrupole field disturbances amplitude.

Dipole Magnetic Field Disturbance Effect

For $2 \cdot 10^{-5}$ dipole disturbance at 500 Hz, the extracted spill intensity variation is shown in Fig. 5(a), and the extracted beam distribution in horizontal phase space is shown in Fig. 5(b) while ignoring other disturbances.

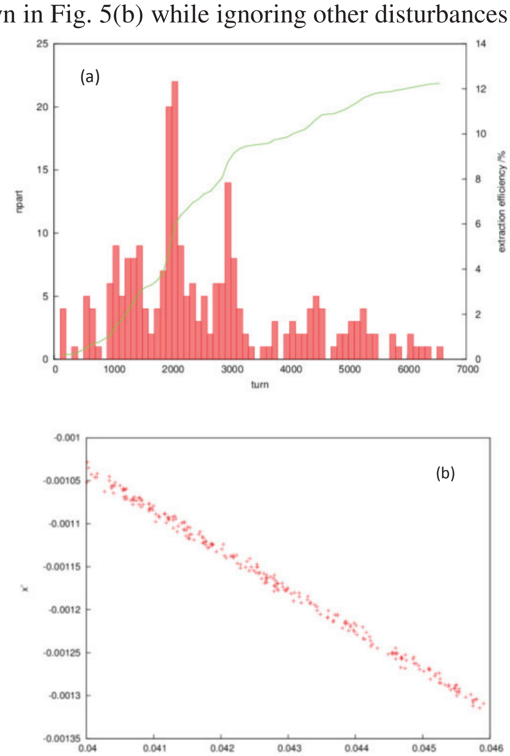

Figure 5: Extracted spill intensity vs. revolution turn (a) and distribution in horizontal phase space (b) under $2 \cdot 10^{-5}$ dipole field disturbance at 500 Hz

As the simulation showed above in comparing to quadruple, $2 \cdot 10^{-5}$ dipole filed disturbance affect less to either the extracted beam spill intensity or the emittance in CSRm besides a largish influence on the spiral step.

CONCLUSION

Considering the discrete variation of the extracted beam spill intensity and hardly compressed beam size on external targets, we evaluated the ditrubance effect of CSRm current magnet power supplies ripple level in RF-Knockout assisted third-order resonant extraction by simulation. The study shows that the extracted spill intensity and the horizontal beam emittance are strongly modulated by $1 \cdot 10^{-4}$ quadruple field disturbance while the dipole's contributes less except for to the spill spiral step. And the disturbance of sextuples can be ignored. Simulation suggests that most disadvantage perturbation can be suppressed by decreased the quadruple field disturbance to below $1 \cdot 10^{-5}$ level.

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