ISBN: 978-3-95450-184-7 doi:10.18429/JACoW-IPAC2018-MOPMF018

NUMERICAL SIMULATION OF SPIN DYNAMICS WITH SPIN FLIPPER IN RHIC

P. Adams, F. Meot, H. Huang, J. Kewisch, P. Oddo, V. Ptitsyn, V. Ranjbar, G. Robert-Demolaize and T. Roser, Collider-Accelerator Department, BNL, Upton, NY 11973, USA

Abstract

Spin flipper experiments during RHIC Run 17 were performed to study its effectiveness as a method for polarization sign reversal during stores. Numerical simulations are reported here, which were performed in accompaniment of these, and are being pursued with the aim of accurately reproducing the experimental conditions and providing thorough insight in the role of various key parameters participating in the dynamics of the spin flip, such as the sweep rate of the AC dipole, chromatic orbit control at RHIC snakes, RF parameters, possible effects of non-linear spin resonances, mirror resonance, tolerance on flipper magnet parameters , etc.
The ultimate goal is for these simulations to serve as a guidance toward perfect flip ($P_f/P_i \approx -1$) to allow routine use during physics Runs.

INTRODUCTION

Spin physics programs in the Relativistic Heavy Ion Collider (RHIC) and in the future electron ion collider eRHIC require measurement of bunch polarization with great accuracy which requires reducing systematic errors. One mean to achieve that consists in frequent reversal of bunch polarization during detector data taking. This can be done without harming beam polarization by using a spin flipper, a device which reverses the polarization sign of all bunches without changing other beam parameters or machine settings.

SPIN FLIPPER

RHIC spin flipper magnet assembly is located in one of the straight sections of the Blue ring. It consists of four horizontal dipoles ("spin rotator") and five vertical AC dipoles (Fig. 1).

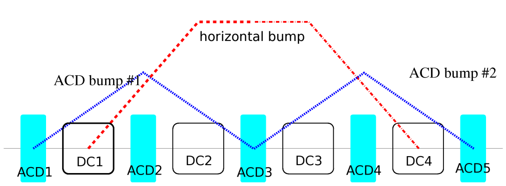

Figure 1: Spin Flipper layout

The four y-rotator dipoles (vertical field) are DC, with field integral $B_{dc}L$. They yield spin rotation angles $+\psi_0/-\psi_0/-\psi_0/+\psi_0$ respectively, with

$$\psi_0 = (1+G\gamma)\frac{B_{dc}L}{B\rho} \tag{1}$$

Orbit-wise this defines a closed local horizontal bump and, spin-wise, it leaves the spin tune $\nu_s \approx 1/2$ unchanged.

The horizontal magnetic field in the AC dipoles has the form $B_{osc}(t) = \hat{B}_{osc}\cos(2\pi f_{osc}(t)t + \varphi_0)$ with $f_{osc}(t)$ the time-varying oscillation frequency and φ_0 a reference phase. ACD1-3 and ACD3-5 triplets both ensure the same $+\phi_{osc}(t)/-2\phi_{osc}(t)/+\phi_{osc}(t)$ spin x-rotation sequence, with

$$\phi_{osc}(t) = (1+G\gamma)\frac{B_{osc}(t)L}{B\rho} \tag{2}$$

Orbit-wise, each triplet ensures a locally closed vertical orbit bump (Fig. 1). The phases of the first (ACD1-3) and second (ACD3-5) vertical bumps are correlated, namely,

$$\varphi_{0,ACD1-3} - \varphi_{0,ACD3-5} = \pi + \psi_0 \tag{3}$$

This configuration of the AC dipole assembly induces a spin resonance at $\nu_{osc} = \nu_s$, with the phase relationship (Eq. 3) canceling the image resonance at $1-\nu_s$, therefore ensuring single resonance crossing and full spin flip (isolated resonance crossing in the presence of the image resonance instead, would otherwise require moving ν_s away enough from $\frac{1}{2}$ which is not viable at RHIC [1]).

SPIN FLIP EFFICIENCY

Froissard-Stora formula describes the spin flip efficiency for the single resonance crossing,

$$P_f = P_i\left(2\exp^{-\frac{\pi}{2}\frac{|\epsilon|^2}{\alpha}} - 1\right) \tag{4}$$

where P_i and P_f the initial and asymtotic polarizations. The strength of the spin resonance excitation is

$$|\epsilon| = \frac{\phi_{osc}}{\pi}\sin\psi_0\sin\frac{\psi_0}{2} \tag{5}$$

The crossing speed (rate of sweep of ν_{osc} through $\nu_s \approx \frac{1}{2}$) is

$$\alpha = \frac{\Delta\nu_{osc}}{d\theta}, \quad d\theta = 2\pi N \tag{6}$$

with $\Delta\nu_{osc}$ the AC dipole frequency span and N the number of turns of the sweep.

SPIN TUNE OSCILLATIONS AND MULTIPLE RESONANCE CROSSINGS

The synchroton motion induces the spin tune ν_s oscillations [2] [3] [4],

$$\delta\nu_s = \frac{1+G\gamma}{\pi}\Delta D'\frac{\Delta p}{p} \tag{7}$$

ISBN: 978-3-95450-184-7 doi:10.18429/JACoW-IPAC2018-MOPMF018

where $\Delta D'$ is a difference of the dispersion function derivatives at the two snakes. Since the AC dipole frequency is linearly swept across ν_s this effect is liable to induce multiple crossing of the resonance (Fig. 2) and thus cause polarization loss during the spin flip.

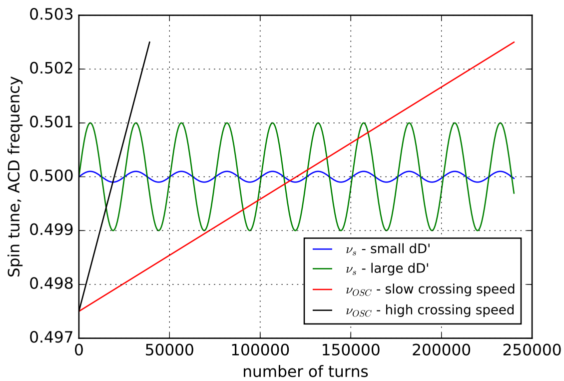

Figure 2: Spin Tune Oscillations cause multiple resonance crossings for large $\Delta D'$ and small crossing speed

SYNCHROTRON MOTION

Angular frequency of synchrotron oscillations [5] is given by

$$\Omega_s = \frac{c}{R}\sqrt{\frac{h\eta\cos(\phi_s)q\hat{V}}{2\pi E_s}} \tag{8}$$

A period of synchrotron motion is $\approx$ 10,000 turns at injection and $\approx$ 20,000 turns at 255 GeV for current RHIC values.

Typically particles undergo several periods of this motion during the spin flip.

SIMULATIONS - SINGLE PARTICLE TRACKING

Tracking of single particle and deriving its spin tune from the longitudinal motion using Eq. 7 was done to demonstrate multiple resonance crossings and its effects on the spin flip. Figure 3 shows how different crossing speeds can affect the spin. Two plots differ only by the crossing speed. Particle‘s initial coordinates are the same (the initial spin is +1 vertically). The slow crossing speed example shows that the spin tune is equal to ACD frequency multiple times and the particle’s spin is affected accordingly.

SIMULATIONS - MULTIPLE PARTICLES

Multiple particle (960 particles per bunch) tracking was done using Zgoubi [6] with RHIC run17 magnet lattice at 23.8 GeV (injection) and 255 GeV (store) energy [2]. Dual 9MHz and 197MHz RF systems, RHIC typical beam emittances, betatron tune and chromaticities were used. The initial spin was chosen to be +1 vertically for all the particles (parallel with the stable spin direction), which leads to the initial polarization P_i=+1. The final polarization P_f

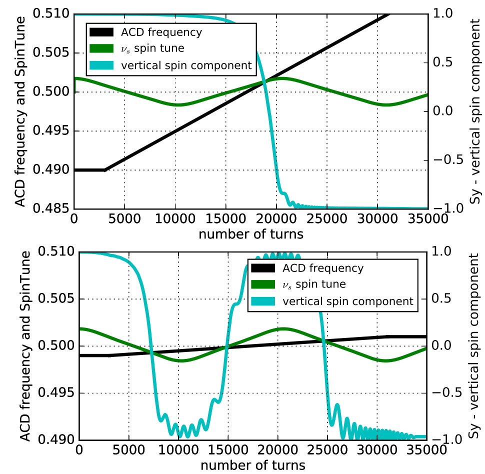

Figure 3: Single (top) vs. Multiple (bottom) resonance crossings

was obtained as a vector sum of the individual particle’s vertical spin components. Figure 4 shows the vertical spin component as a function of time (number of turns).

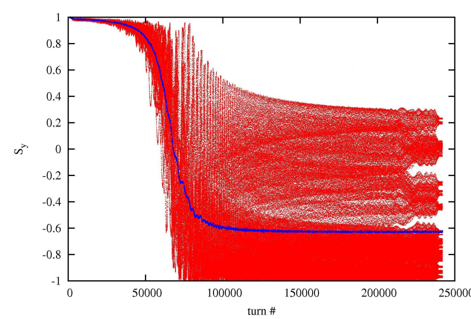

Figure 4: Vertical spin component. Red - vertical spin component of 40 different particles. Blue - an averaged vertical spin component of 960 particles.

SPIN FLIPPER DURING RHIC RUN 17

Sweep time, time period during which the AC dipole frequency is changing, was varied between 0.5 s and 3.0 s (RHIC revolution frequency is 78 kHz).

The AC dipole frequency span was tuned to $\Delta\nu_{osc}$=0.005.

Difference of the dispersion function derivatives at the two snakes $\Delta D'$ was scanned down to 3 mrad at injection and 0.1 mrad at 255 GeV from starting at $\approx$ 50 mrad.

The strength of the spin resonance $|\epsilon|$ was setup to 0.0002397 at injection and 0.0005682 at 255 GeV.

SWEEP TIME SCAN

The simulations suggest that Froissard-Stora formula dominates the spin flip efficiency for high crossing speeds (small sweep time values) and multiple resonance crossings are likely to be accountered at low crossings speeds (high sweep time values) - Fig. 5.

ISBN: 978-3-95450-184-7 doi:10.18429/JACoW-IPAC2018-MOPMF018

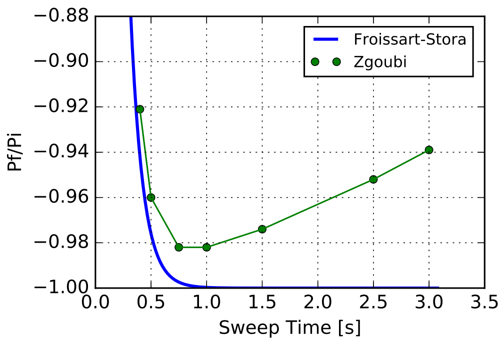

Figure 5: Sweep Time scan at injection energy ($G\gamma$=45.5). 1 s is equivalent to 78k turns. $\Delta\nu_{osc}$=0.005, $\Delta D'$=3 mrad are achieved RHIC values. The Froissard-Stora resonance strength $|\epsilon|$ is 0.0002397 at injection.

ΔD′ SCAN

Lower values of $\Delta D'$ lead to decrease of the spin tune spread. Simulations show that reduction of $\Delta D'$ should to be an useful tool for improving the spin flip efficiency ($P_f/P_i = -0.98$ for 3 s and $P_f/P_i = -0.99$ for 1 s with $\Delta D'$ set to 0.005 mrad) - Fig. 6.

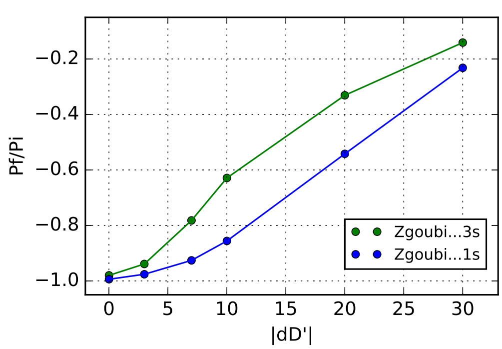

Figure 6: $\Delta D'$ scan at injection energy ($G\gamma$=45.5) $\Delta\nu_{osc}$=0.005, sweep time is 1 s (78k turns) and 3 s (234k turns).

CONCLUSIONS

The goal of the simulations is to understand effects of various parameters onto the spin flip and optimize them the way that the best possible spin flip efficiency is achieved. More simulations needs to be done to study the orbit effects and tolerance on spin flipper magnets.

ACKNOWLEDGEMENTS

Work supported by Brookhaven Science Associates, LLC under Contract No. DE-AC02-98CH10886 with the U.S. Department of Energy.

REFERENCES

[1] M. Bai and T. Roser, “Full Spin Flipping in the Presence of Full Siberian Snake”, Phys. Rev. ST Accel. Beams 11, 091001 (2008).

[2] F. Méot *et al.*, “RHIC Spin flipper, fast-sweep efficiency simulations”, BNL-114167-2017-IR, C-A/AP/589 (2017).

[3] F. Kewisch *et al.*, “Correction of the spin chromaticity in RHIC”, BNL-99842-2013-IR, C-A/AP/478 (2013).

[4] M. Bai, V. Ptitsyn, T. Roser, “Impact on Spin Tune From Horizontal Orbital Angle Between Snakes and Orbital Angle Between Spin Rotators”, BNL-81721-2008-IR, C-A/AP/334 (2008).

[5] D.A. Edwards, M.J. Syphers, “An Introduction to the Physics of High Energy Accelerators”, A Wiley-Interscience Publication, 1993.

[6] F. Méot, “The ray-tracing code Zgoubi”, NIM-A 427 (1999) 353-356 ; http://sourceforge.net/projects/zgoubi/