SPIN DECOHERENCE IN THE FROZEN SPIN STORAGE RING METHOD OF SEARCH FOR A PARTICLE EDM

A.E. Aksentyev[1,2,3], Y.V. Senichev[3]

[1] National Research Nuclear University "MEPhI," Moscow, Russia
[2] Institut für Kernphysik, Forschungszentrum Jülich, Jülich, Germany
[3] Institute for Nuclear Research of the Russian Academy of Sciences, Moscow, Russia

INTRODUCTION

Spin coherence refers to a measure of preservation of polarization in an initially polarized beam. The spin vector of a particle injected into a storage ring starts to precess about the vertical magnetic field vector in accordance with the Thomas-BMT equation.

The precession frequency is dependent on the equilibrium-level energy, which differs across the beam particles. This does not pose a problem when the initial polarization is vertical; however, the Frozen Spin Storage Ring EDM search method requires beam polarization along the momentum vector, i.e., in the horizontal plane.

In the present work we analyze the source of decoherence, and investigate the way it can be suppressed in the horizontal plane in a perfectly aligned ring by means of sextupole fields. We also consider the case of an imperfect ring: transference of decoherence into the vertical plane induced by vertical plane spin precession, and the effect of sextupole fields.

ORIGIN OF DECOHERENCE

A particle's spin tune depends on its equilibrium-level energy, expressed by the Lorentz factor:

$$\begin{cases} \nu_s^B &= \gamma G, \\ \nu_s^E &= \frac{G+1}{\gamma} - \gamma G. \end{cases}$$

As a consequence of the phase stability principle, particles having longer orbits must possess higer equilibrium energy levels; else they'd fall from the bunch.

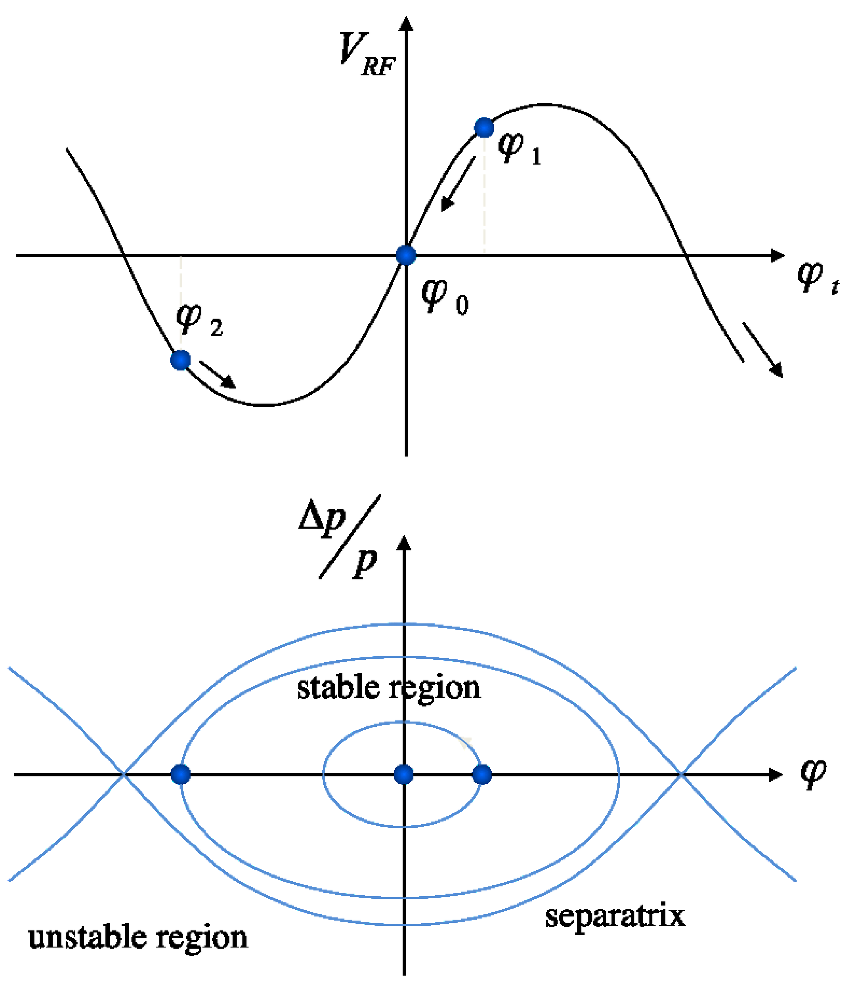

Figure 1: Linear theory

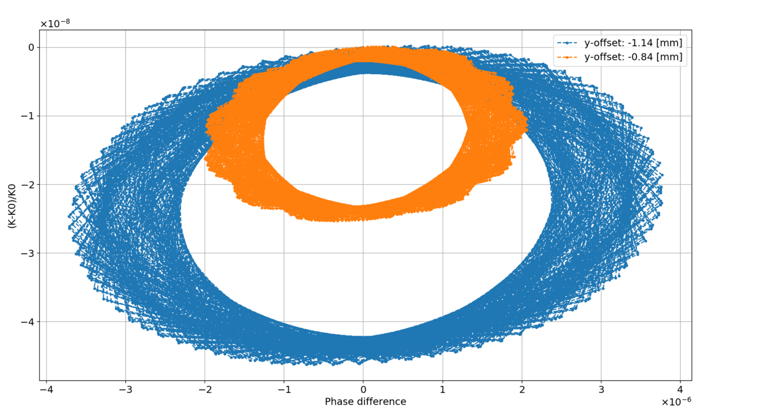

Figure 2: 3rd order transfer maps. Observe equilibrium level energy offset

PERFECT LATTICE

- Beam energy 270 MeV;
- spin precession axis $\bar{n} = \hat{y}$;
- $\nu_s(z) = \sum_{k=0}^{5} a_k \cdot z^k + O(z^6)$;
- minimize coefficient a_2 to remove quadratic dependence.

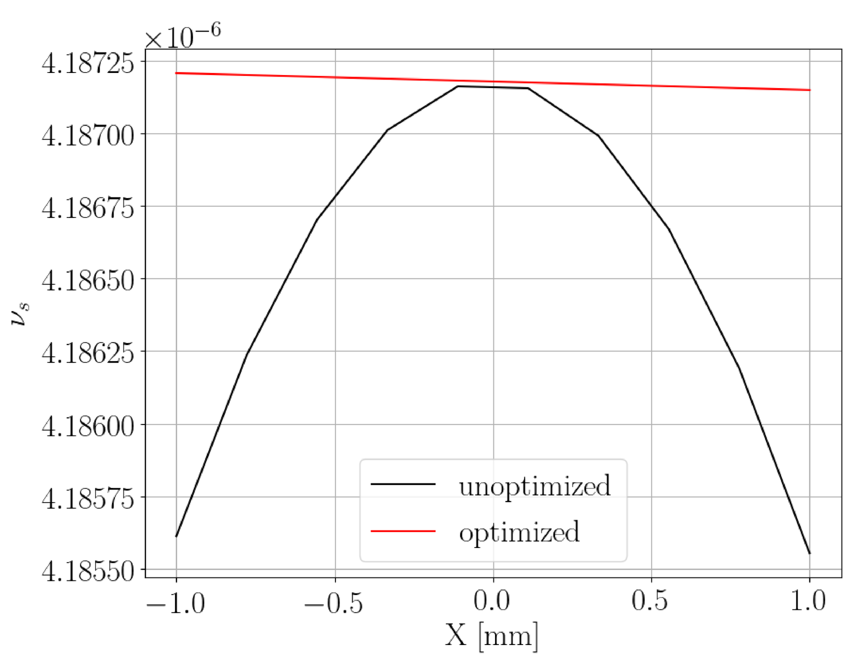

Figure 3: Spin tune dependence on horizontal offset

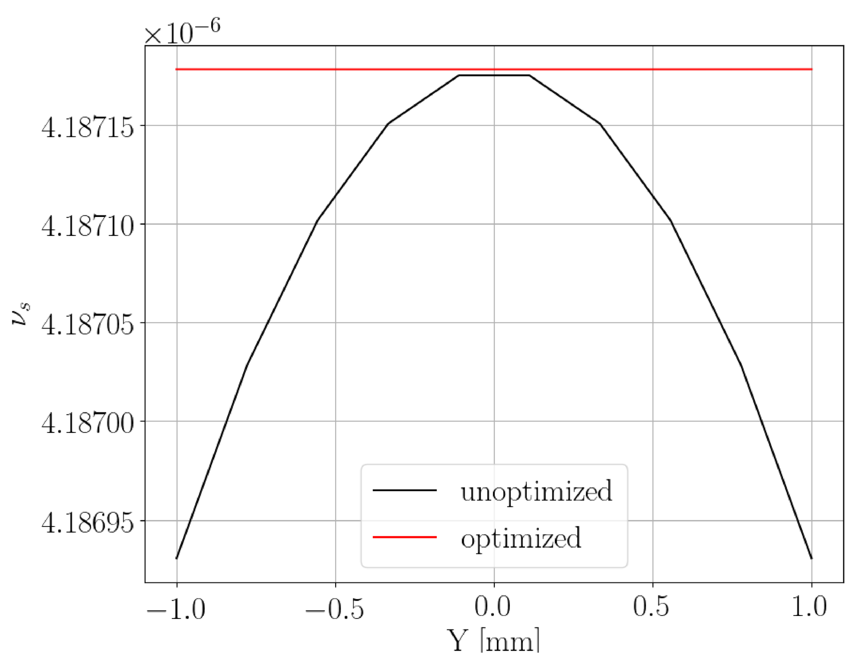

Figure 4: Spin tune dependence on vertical offset

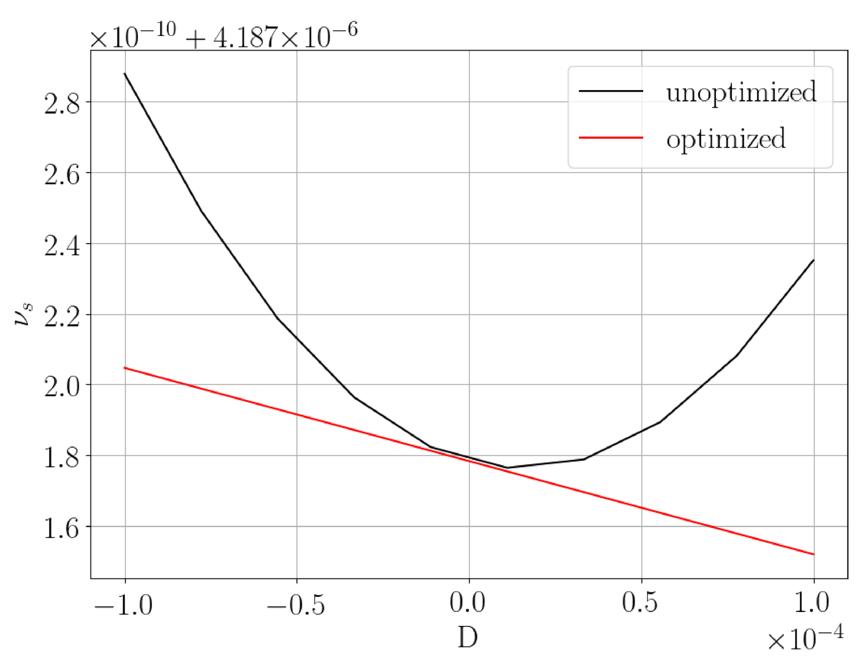

Figure 5: Spin tune dependence on energy offset

EFFEFCTIVE LORENTZ FACTOR

Betatron motion orbit lengthening and synchrotron oscillations cause an equilibrium-level momentum shift

$$\Delta\delta_{eq} = \frac{\gamma_0^2}{\gamma_0^2\alpha_0 - 1}\left[\frac{\delta_m^2}{2}\left(\alpha_1 - \alpha_0\gamma^{-2} + \gamma_0^{-4}\right) + \left(\frac{\Delta L}{L}\right)_\beta\right],$$

where δ_m is the amplitude of synchrotron oscillations.

The corresponding *effective* Lorentz factor

$$\gamma_{eff} = \gamma_0 + \beta_0^2\gamma_0 \cdot \Delta\delta_{eq},$$

where γ_0, β_0 are the Lorentz factor and normalized speed of the reference particle.

SEXTUPOLE DECOHERENCE SUPPRESSION

A sextupole of strength

$$S_{sext} = \frac{1}{B\rho}\frac{\partial^2 B_y}{\partial x^2}$$

modifies both the momentum compaction factor

$$\Delta\alpha_{1,sext} = -\frac{S_{sext}D_0^3}{L},$$

and the particle orbit length

$$\left(\frac{\Delta L}{L}\right)_{sext} = \mp\frac{S_{sext}D_0\beta_{x,y}\varepsilon_{x,y}}{L}.$$

Here $D(s,\delta) = D_0(s) + D_1(s)\delta$ is the dispersion function.

IMPERFECT LATTICE

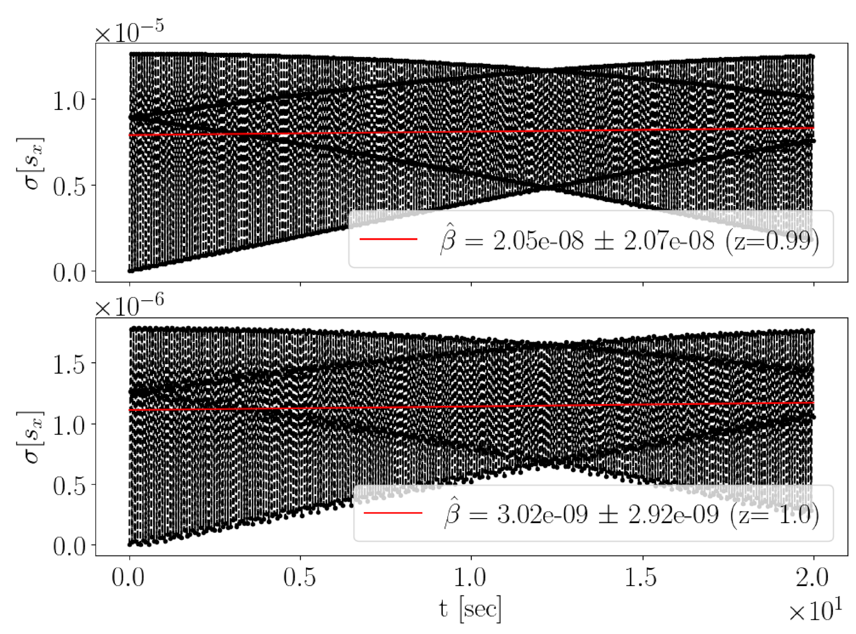

Figure 6: Decoherence in the horizontal plane. Top panel: sextupoles are off; bottom panel: sextupoles are on.

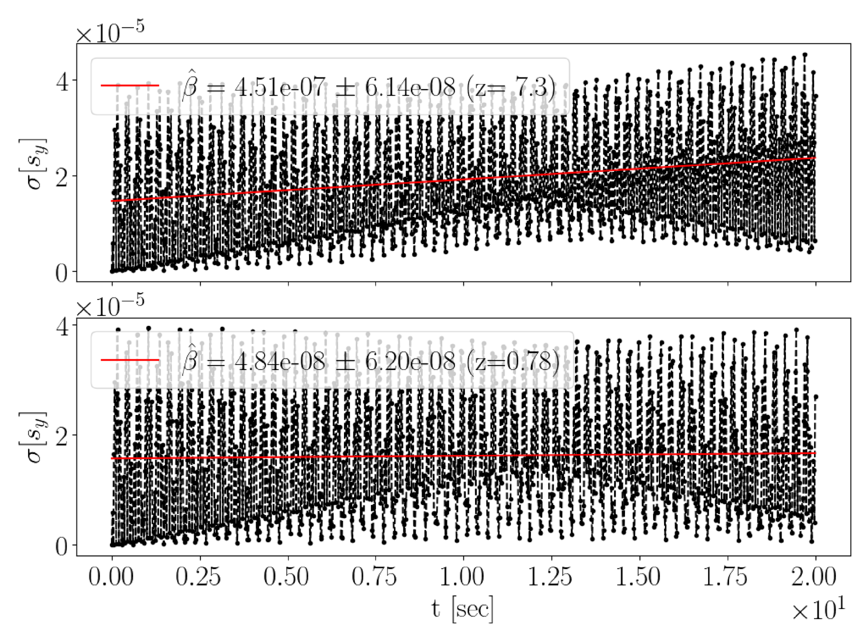

Figure 7: Decoherence in the vertical plane. Top panel: sextupoles are off; bottom panel: sextupoles are on.

CONCLUSIONS

1. Decoherence is a result of betatron and synchrotron oscillations of beam particles;
2. In an imperfect lattice, there's no decoherence in the horizontal plane, but it transfers into the vertical plane;
3. Sextupole fields can remove the parabolic dependence of spin tune on particle phase space coordinates;
4. Linear decoherence effects need further study; the working hypothesis is that they can be suppressed by adjusting the RF cavity parameters.