ISBN: 978-3-95450-240-0 ISSN: 2673-5539 doi:10.18429/JACoW-RuPAC2021-TUPSB11

NUMERICAL INVESTIGATION OF THE ROBUSTNESS OF SPIN-NAVIGATOR POLARIZATION CONTROL METHOD IN A SPIN-TRANSPARENT STORAGE RING

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Abstract

The robustness of spin-navigator based method for manipulating the beam polarization axis has been investigated with respect to bend magnet installation errors. Toward that end, variation of the invariant spin axis components along the beamline of an imperfect storage ring operating in the spin-transparent mode has been estimated. The beam polarization vector behavior in the given lattice has been investigated. Conclusions are made regarding the feasibility of using "spin navigator" solenoids for defining the beam polarization axis in the detector region.

INTRODUCTION

In the proposed method of polarization control in a spin-transparent (ST) mode spin precession frequency is set close to zero with the help of "siberian snakes". Since particles are in the vicinity of an integer resonance, "navigator" solenoids with weak fields are used for stabilization of polarization direction (Fig. 1) [1]. They consist of solenoids with longitudinal field and magnets with radial field rotating spin-vectors of particles by small angles. In ST method one can obtain any polarization direction at any point of an orbit for arbitrary beam energy.

This method of polarization control is highly sensitive to errors. That is why it is necessary to investigate its robustness in the numerical simulation. The stabilizing influence of navigator solenoids in the vicinity of an integer resonance should be larger than the influence of effects arising from lattice imperfections. Spin-orbit dynamics simulations using NICA lattice were made below to estimate the influence of magnet tilts on the ability to guide polarization direction with navigator solenoids in the detector.

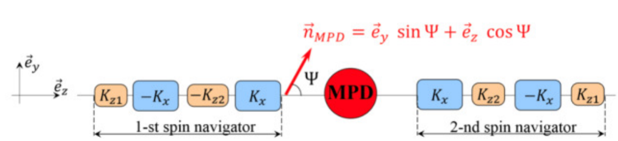

Figure 1: The scheme of navigator solenoids location close to MPD detector [1].

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METHOD "SPIN-KICK"

When the bending magnets are rotated around the optical axis it is necessary to compensate the vertical component of the guiding field to preserve the closed orbit. The latter will not be flat if the radial components of magnetic field are present. In the simulation a simplifying assumption was used that orbital dynamics does not change with magnet tilts but spin transfer matrix of an element is rotated by an angle depending on a tilt. All the results obtained with this assumption can be interpreted without the loss of generality in the frame of estimation of ST method robustness and feasibility.

Spin dynamics of particles in a laboratory frame is described by T-BMT equation:

$$\frac{d\vec{S}}{dt} = \vec{S} \times (\vec{\Omega}_{MDM} + \vec{\Omega}_{EDM}),$$

$$\vec{\Omega}_{MDM} = \frac{q}{m\gamma}\left[(\gamma G + 1)\vec{B}_{\perp} + (1 + G)\vec{B}_{\parallel} - \gamma\left(G + \frac{1}{\gamma + 1}\right)\frac{\vec{\beta} \times \vec{E}}{c}\right],$$

$$\vec{\Omega}_{EDM} = \frac{q\eta}{2m}\left[\vec{\beta} \times \vec{B} + \frac{\vec{E}}{c}\right],$$

where $\vec{\Omega}_{MDM}$ and $\vec{\Omega}_{EDM}$ are spin-vector $\vec{S}$ precession frequencies, caused by the presence of magnetic and electric dipole moment of particles – MDM and EDM respectively. G is the anomalous magnetic moment, γ – Lorentz factor. $\vec{B} = \vec{B}_{\parallel} + \vec{B}_{\perp}$, $\vec{B}_{\parallel} = \frac{\vec{v}\cdot\vec{B}}{v^2}\vec{v}$.

In the case of a purely magnetic lattice ($E = 0$) and taking into account that $\Omega_{EDM} \ll \Omega_{MDM}$, in the rest frame:

$$\vec{\Omega}_{MDM} = \frac{q}{m\gamma}[\gamma G\, \vec{B}_{\perp} + (1 + G)\vec{B}_{\parallel}].$$

In the case of bend magnet tilts around the optical axis of the accelerator $B_{\parallel} = 0$. In linear approximation the vertical precession frequency does not change. The radial component $\Delta\Omega_{MDM}$ emerges that is equivalent to spin-vector rotation around the radial axis by an angle ψ:

27th Russ. Part. Accel. Conf. RuPAC2021, Alushta, Crimea JACoW Publishing
ISBN: 978-3-95450-240-0 ISSN: 2673-5539 doi:10.18429/JACoW-RuPAC2021-TUPSB11

$$\psi = \frac{\alpha R}{v} \cdot \Delta\Omega_{MDM} = \frac{\alpha R}{v} \cdot \frac{qG}{m} B\sin(\varphi),$$

where α and R – the angular size and trajectory radius of a particle in the magnet, B – guiding field, φ – random angle of a tilt around the longitudinal axis.

NUMERICAL INVESTIGATION OF SPIN-ORBITAL DYNAMICS

For numerical modeling the program software COSY INFINITY was used. It is based on differential algebraic approach for optimization of transfer map calculation. The latter are calculated for orbital and spin motion separately.

In the model the beam consisting of 100 deuterons was injected with $\gamma = 1.14$. The particles were uniformly distributed from -2 to 2 mm in a transverse radial direction. The initial polarization is longitudinal.

Dipole magnets were rotated by angles $\varphi \sim N(0, 10^{-4})$. The RMS error $\sigma(\varphi)$ is expressed through the error of magnet installation heights $\sigma(h)$ and the length of a magnet L: $\sigma(\varphi) = \sigma(h)/L$. With $\sigma(h) \sim 100$ um and $L \sim 1$ m, $\sigma(\varphi) \sim 10^{-4}$.

In the setting with $\varphi \sim N(0, 10^{-4})$ the relative change of a spin-tune and longitudinal polarization $\Delta\nu/\nu \sim 10^{-3}$, $\Delta P/P \sim 10^{-5}$. These values are caused by nonzero realization of math. expectation value in a finite sampling and, as a consequence, the emergence of nonvanishing Y projection of invariant axis N_y in the detector region. It can be explained in the following way: vertical polarization arises from magnet tilts along the ring. Then the latter is rotated into the ring plane by a half-snake solenoid before detector region. This is equivalent to rotation of spin-vectors around Y axis after one turn or $\Delta N_y \neq 0$ in a detector.

The expectation value of tilt angles was shifted by $\pm 10^{-3}$ rad to investigate the robustness of spin dynamics. In this setup $\Delta\nu/\nu \sim 10^{-2}$, $\Delta P/P \sim 10^{-4}$, $\Delta N_y \sim 10^{-2}$ (Fig. 2, 3, 4).

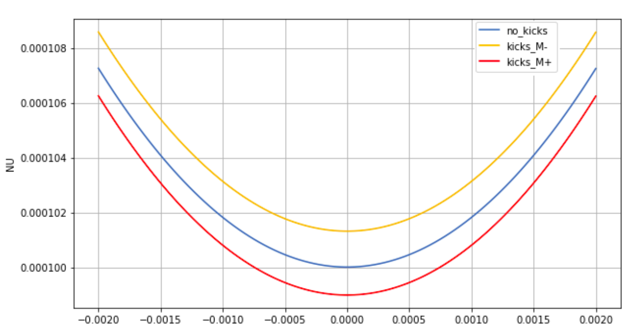

Figure 2: Spin-tune for different transversely offset particles for ideal lattice and with magnet tilts around the longitudinal axis $\varphi \sim N(\pm 10^{-3}, 10^{-4})$.

In Fig. 2 the spin-tune of a reference particle coincides with the necessary value 10^{-4} set by navigator solenoids to provide stable polarization control [1]. The parabolic dependence of spin-tune on a particle transverse position in a bunch comes from the orbit lengthening effect. It leads to different effective energies and spin-tunes due to synchronous acceleration principle [2].

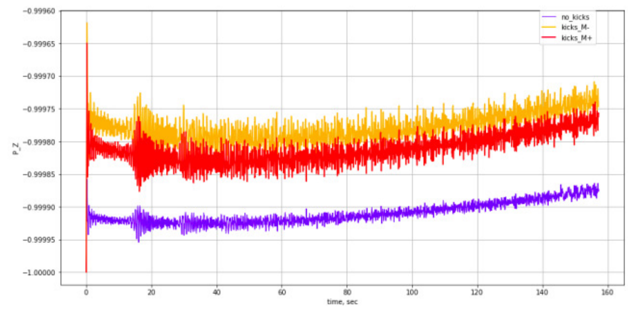

Figure 3: The time dependence of a longitudinal beam polarization in the detector point for ideal lattice and with magnet tilts around the longitudinal axis $\varphi \sim N(\pm 10^{-3}, 10^{-4})$.

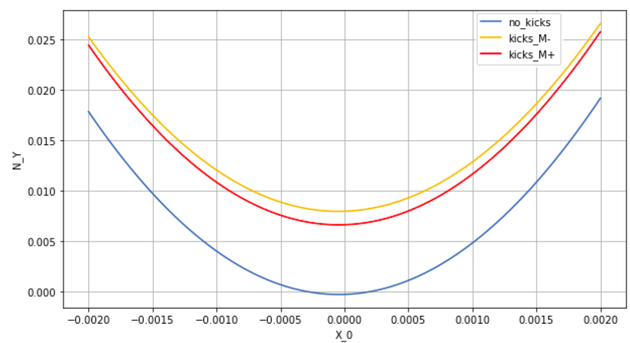

Figure 4: The dependence of a vertical component of the invariant axis N_y in the detector point for different transversely offset particles for ideal lattice and with magnet tilts around the longitudinal axis $\varphi \sim N(\pm 10^{-3}, 10^{-4})$.

CONCLUSION

The principal ability of beam polarization control with navigator solenoids was demonstrated in a structure with lattice imperfections such as bending magnet rotations. The main effect arising from magnet tilts is the emergence of a vertical component of invariant spin axis in the detector point. It was explained first and then shown in the numerical experiment. The qualitative character of spin dynamics is preserved that means that the spin motion remains stable in the vicinity of an integer spin resonance corresponding to ST regime.

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