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MODELING OF THE SPIN-NAVIGATOR METHOD FOR MANIPULATING THE BEAM POLARIZATION IN A SPIN-TRANSPARENT STORAGE RING

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Abstract

A method for manipulating the orientation of the beam polarization axis based on using the so-called "spin-navigator" technique in a storage ring operating in the spin-transparent regime has been modelled. The beam particles' spin- and orbital dynamics have been numerically investigated with the purpose of determining the method's feasibility; the latter's effect on spin-decoherence has been studied also.

INTRODUCTION

In the projected method for the manipulation of the beam polarization, the spin-transparent (ST) regime is effected by means of "Siberian snakes" which set the beam particles' spin precession frequencies close to zero (in the beam rest frame). Practically, this means that the spin-vector of a particle on the closed orbit (CO) coincides with itself after passing the accelerator lattice sequence (see Fig. 1). The additionally used "spin-navigating" solenoids (Fig. 2) have a two-fold purpose: not only to orientate the polarization axis, but also to stabilize this orientation by slowly turning the beam particles' spin-vectors about it, thus offsetting the "zero spin precession frequency" condition [1].

However, the finiteness of the beam phase space volume prevents the simultaneous satisfaction of the "zero precession frequency" condition by all beam particles. Due to the differences in their spin-orbit motion the particles' spin-vectors diverge (which phenomenon is termed "spin-decoherence"), which causes depolarization of the beam. One must meet certain conditions, homogenizing the distribution of the spin-precession axis over the beam phase space, in order to preserve the polarization.

The purpose of the present work was to study the beam particles' spin-orbital dynamics in the neighborhood of the zero spin resonance and the determination of whether the spin-navigator method for manipulating the orientation of the beam polarization axis is a feasible option. To that end, the COSY INFINITY modeling environment was used [2]. Depolarization mechanisms, in particular those specific to the proposed polarization manipulation method, have been considered.

MODELLING RESULTS

Numerical modeling has been done using the COSY INFINITY [2] modelling environment. We used three bunches

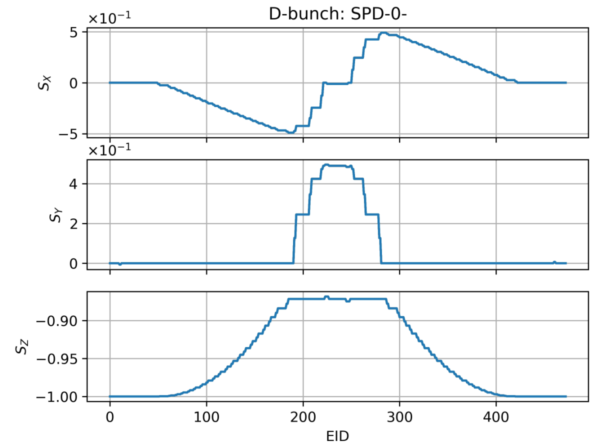

Figure 1: Transformation of the reference particle's spin-vector coordinates during one revolution in the accelerator lattice. The ordinal numbers (EID) on the horizontal axis indicate the element just passed. The particles whose spin-vector coordinates are represented in the figure have only energy deviation $\delta = {}^{\Delta K}/_{K}$ from the reference particle at injection, which is indicated by the words "D-bunch"; the words "SPD-0-" indicate that the spin-vectors of all particles pointed backwards along the reference particle's momentum vector.

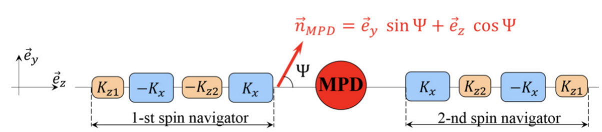

Figure 2: Spin-navigator placement scheme in the MPD-detector section [1].

of $N = 300$ particles each for a sufficiently precise beam polarization estimate

$$\boldsymbol{P} = \frac{1}{N}\sum_{j=1}^{N} \boldsymbol{s}^{(j)}.$$

Particles were uniformly distributed in phase space at injection:

1. X- and Y- bunches: $x, y = \pm 2$ mm respectively (the other phase-space coordinates set to zero);
2. D-bunch: $\delta = {}^{\Delta K}/_{K} = \pm 2 \cdot 10^{-4}$ (same as above).

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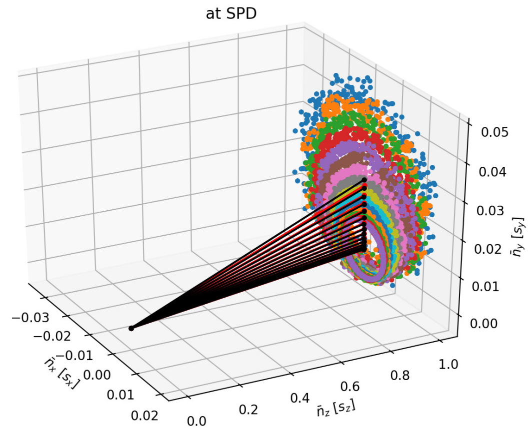


Figure 3: Mean spin-vector $\langle \boldsymbol{s} \rangle$ (or, what is the same, invariant spin axis $\bar{n}$) orientations at the SPD-detector for particles with varying initial offsets from the closed orbit in the radial direction at injection. Colored dots indicate the ellipses the spin-vectors describe during precession.

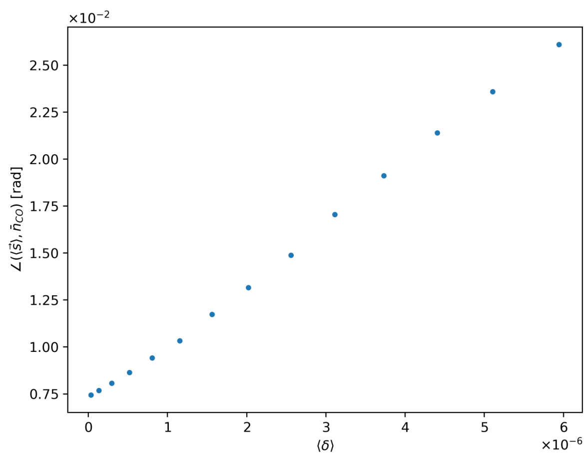
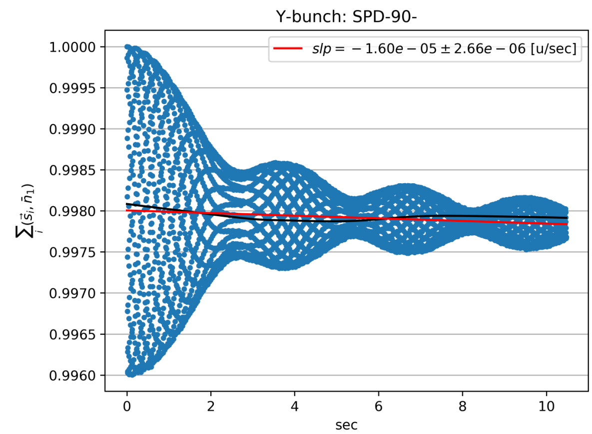
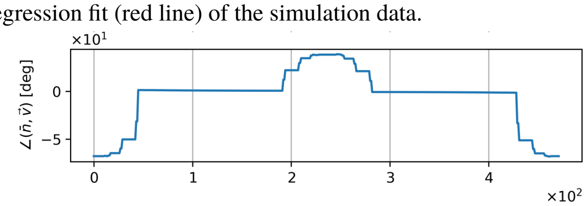


Figure 4: The angle of tilt of a non-reference particle's invariant spin axis from that of the reference particle as a function of the offset particle's mean kinetic energy offset.

The study results can be summarized in the following: a beam particle's spin-vector precesses along the surface of a cone (Fig. 3) whose **(a)** spray angle, as well as the **(b)** angle of deviation of its axis from the direction defined by the invariant spin axis $\bar{n}_{CO}$ of the particle on the closed orbit (Fig. 4), depend on the mean value of its kinetic energy deviation $\langle\delta\rangle = \langle\Delta K/K\rangle$. This value also determines the **(c)** spin precession frequency. The three parameters **(a)**, **(b)**, **(c)** also determine, in the general case, the rapidity of the beam depolarization process caused by spin-decoherence. Initially, four major cases of orientation of the beam polarization axis had been checked: up, down, forward (along the momentum vector), backward. In the majority of observed cases, spin-decoherence was not an issue (see Fig. 5 for a typical simulation result); however, a case of rapid depolarization (Fig. 6) was observed for the "polarization-up" case.

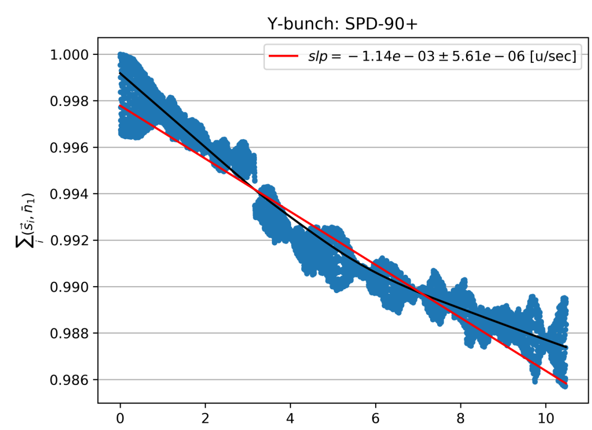


(a) The beam polarization as a function of time. The legend specifies the depolarization speed as estimated by the slope of a linear regression fit (red line) of the simulation data.

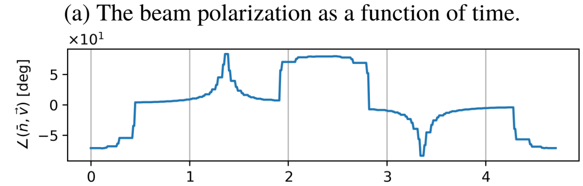


(b) The $\bar{n}$ tilt distribution within the lattice sequence. The distribution is *symmetric* with respect to the lattice sequence's median.

Figure 5: The stable case.



(a) The beam polarization as a function of time.



(b) The $\bar{n}$ tilt distribution within the lattice sequence. The distribution is *asymmetric* with respect to the lattice sequence's median.

Figure 6: The unstable case.

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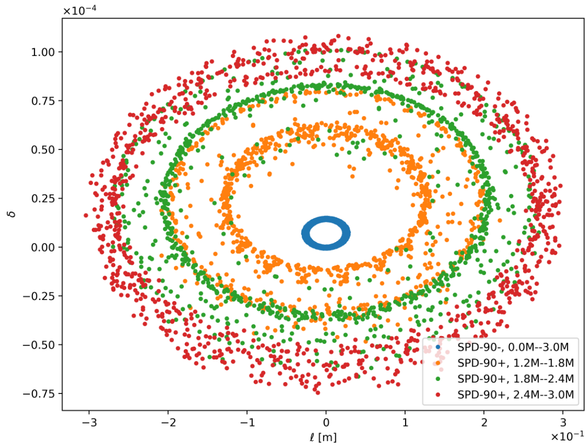

Figure 7: Longitudinal beam phase-space ellipse in the stable and unstable cases, with the latter split into three beam-revolution subranges, denoted by color.

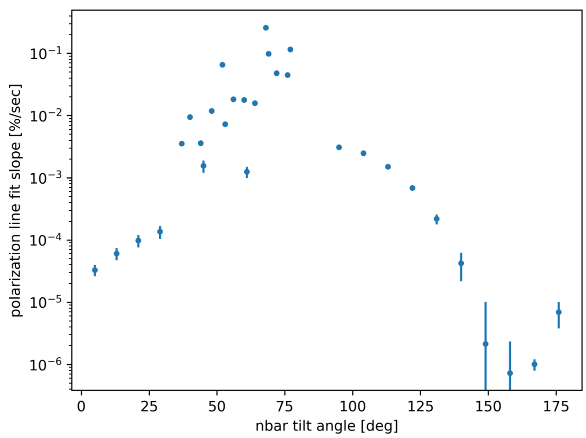

Figure 8: Meta-study results showing the dependence of depolarization rapidity as a function of the orientation of the polarization vector at the SPD-detector.

STUDY OF INSTABILITY

Upon encountering a case of phase-space instability (see Fig. 7), an additional meta-study checking a range of orientations was carried out (Fig. 8). The study suggests phase-space instabilities might be effected by the spin-navigators' mode of operation: the latter operate by creating an asymmetry in the magnetic field distribution in the straight sections of the storage ring. In Figs. 5b and 6b the polarization axis distributions along the beam line are presented. The distribution in Fig. 6b shows an asymmetry with respect to the median element in the lattice's sequence, which asymmetry is lacking in the stable case (Fig. 5). In fact, the meta-study appears to suggest that there is a direct correlation between the degree of asymmetry in the $\bar{n}(z - z_{median})$ distribution and the depolarization speed. Since the production of the asymmetry is *the means* by which the spin-navigators manipulate the polarization axis, we conclude that there is a definite domain of applicability of the spin-navigator method.

CONCLUSION

The feasibility of using the spin-navigator technique for manipulating the orientation of the beam polarization axis in a storage ring operating in the spin-transparency mode has been confirmed, although its applicability domain appears restricted on account of phase-space stability.

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