MAINTAINING POLARIZATION IN SYNCHROTRONS

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Abstract

The paper describes a method of the preservation of the polarization of the electron beam during the acceleration in a synchrotron. It is proposed to install in the ring equally spaced Siberian Snakes. Advantages to use the odd number of snakes are discussed. Preliminary results of the analytical estimations and of numerical spin tracking simulation are shown.

INTRODUCTION

The polarized beams are needed, first of all, for precise energy calibration using either resonant depolarization or free precession frequency measurement technique; and they are necessary for physics program with longitudinally polarized beams. Acceleration of polarized beams in a synchrotron has many advantages in comparison with the use of self-polarization directly in the collider: 1) full intensity polarized of up to 80%-90% electron beam could be accelerated and used for the experiments; 2) a polarized up to 50%-70% positron beam with only about 10 times lower intensity also should be available – it will become polarized in about 5 min in a 1-1.5 GeV wiggler damping ring; 3) free spin precession frequency measurement technique [1] is much faster and robust method of the energy determination – it measures every injection shot not only the average beam energy with the accuracy in the order of 10^{-6} , but also many other parameters, such as spin de-coherence rate, strength of first and high order synchrotron spin resonances etc.

A method of Siberian Snakes for preservation of the polarization during acceleration in a synchrotron was proposed by Derbenev and Kondratenko in 70-th [2]. They suggested install along a circumference the odd number of 180^0 spin rotators. We will briefly discuss the applicability of that approach for acceleration of the polarized electron and positron beams in a booster synchrotron of FCC-ee collider.

POLARIZED BEAM ACCELERATION WITH SIBERIAN SNAKES

When polarized electron beam is accelerated say from 20 GeV to 80 GeV it crosses more than 130 of integer spin resonances spaced by 440.65 MeV. Due to small field errors it will become fully depolarized even by a single cross of such a resonance. A Siberian Snake may help to solve this problem quite radically.

It is some kind of a spin rotator which rotates spin by 180^0 around any axis which is perpendicular to the vertical one. In a ring with equally spaced odd number of snakes the closed spin orbit looks like it is shown in the Fig. 1 - everywhere in arcs spins are lying in the medium plane of an accelerator.

Another remarkable fact is that with the odd number of snakes the fractional part of the spin tune always equals to ν=0.5, thus all the spin resonances became eliminated! Still strong enough spin perturbation may destroy the regular spin motion making it non-adiabatic. It may happen, if any k-th harmonic amplitude of a perturbation exceeds or approaches to w_k~0.5.

Other mechanism, which one should take into account, is the radiative depolarization. The spin relaxation rate is described by the famous DK formula [3]:

$$\tau_p^{-1} = \frac{5\sqrt{3}}{8} \lambda\!\!\!^{-}_e r_e c \gamma^5 \left\langle \frac{1 - \frac{2}{9}\left(\vec{n}\vec{\beta}\right)^2 + \frac{11}{18}\vec{d}^2}{|r^3|} \right\rangle$$

Here $\vec{n}(\theta)$ is a unity vector aligned along the equilibrium spin direction of a reference particle, $\vec{d}(\theta) \equiv \gamma \frac{\partial \vec{n}}{\partial \gamma}$ is the so-called a spin-orbit coupling vector, which describes the dependence of $\vec{n}$ from the energy, r is the bending radius and other symbols have the obvious meaning.

In a flat normal ring without snakes $\vec{n}(\theta)$ is vertical and $\vec{d}(\theta) = 0$. In the ring with the odd number of snakes $\vec{n}(\theta)$ is horizontal in arcs, as shown in the Figure 1, $\left|\vec{d}\right|$ scales $\sim \gamma$ and $\tau_p^{-1} \sim \gamma^7$.

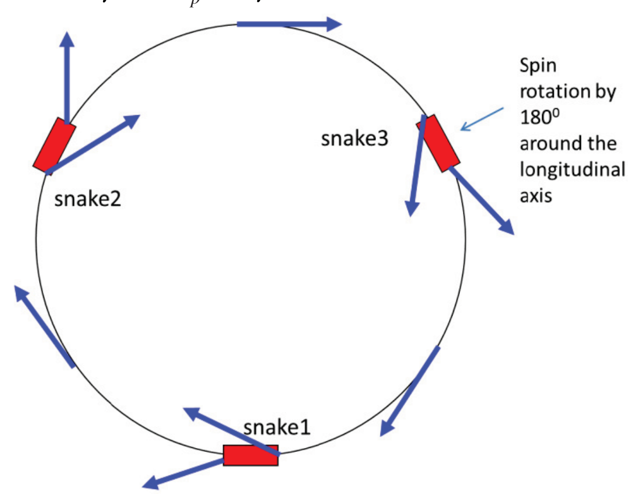

Figure 1: Schematic of spin rotation in a ring by 3 solenoid type snakes.

The averaged over the azimuth θ value of the spin-orbit coupling vector depends on the number of snakes N as follows:

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$$\langle \vec{d}^2 \rangle \simeq \frac{\pi^2}{3}\frac{\nu_0^{\ 2}}{N^2}\ .$$

Here $\nu_0 = \gamma a$ is a spin tune, a is the anomalous magnetic moment.

So, increasing the number of snakes one will reduce the depolarization rate $\tau_p^{-1} \sim N^{-2}$. With 3 snakes in the isomagnetic ring with the bending radius r=11 km τ_p =320 s at E=45 GeV and τ_p =6 s at E=80 GeV – very strong energy dependence! In the Figure 2 it is shown calculated by the code ASPIRRIN [4] dependence of the factor $|d(s)|$ (or equivalently |F5|) along the azimuth s , counted there in meters.

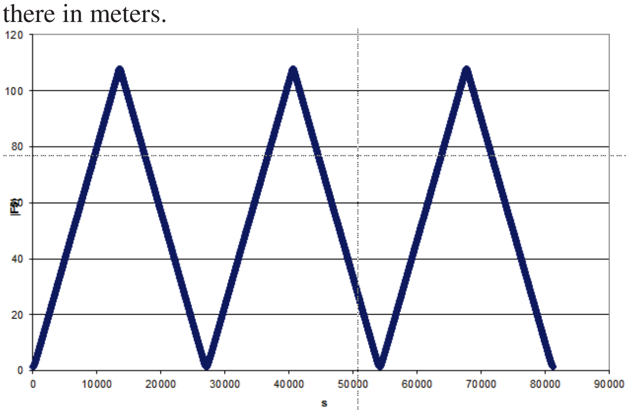

Figure 2: Azimuth dependence of the modulus of the spin-orbit coupling vector $|d(s)|$.

Its linear behaviour is dictated by the chromaticity of the $\vec{n}$ direction in arcs, which is proportional to the factor ν_0 / N , we discussed above.

Let's estimate the polarization loss during acceleration in a synchrotron. Assuming that energy ramp proceeds linearly during a time T one can calculate:

$$\tau_p^{-7} \sim E^7$$

$$P_{rad}(T) = \exp\left(-\int_0^T \frac{dt}{\tau(t)}\right) = \exp\left(-\frac{T}{8\tau_T}\frac{1-\left(\frac{E_0}{E_T}\right)^8}{1-\frac{E_0}{E_T}}\right).$$

For E_0=20 GeV, ET=80 GeV and taken $\tau_T = 6$ s, T=10 s, one gets Prad(T)=0.79 – not too small! With T=20 s the result is also not very bad: Prad(T)=0.79. And even with T=30 s the loss of the polarization during acceleration is only 50%, which may be considered as acceptable.

SOLENOID TYPE SPIN ROTATORS

Different optics schemes for compensation of by the solenoid induced coupling were suggested in 80-th by Litvinenko and Zholentz [5]. Most simple for realization is a scheme shown in the Figure 3. The total solenoid is divided in two halfs. Each half rotates spin around the longitudinal axis by the angle

$$\frac{\varphi}{2} = (1+a)\frac{\int Bdl}{Br}$$

The coupling is compensated by the normal quadrupole lenses inserted between the solenoids providing that the 2x2 transportation matrices satisfy to the condition $T_x = -T_y$.

Main advantage of such a scheme is a flexibility in tuning the optics of a spin rotator. One can switch off the solenoids completely and retune the quads to provide the same beam transport as it was before.

The other requirement comes from the spin transparency condition. To cancel the contribution of the horizontal betatron oscillations to beam depolarization the transport matrix of such a partial spin rotator should be of the type [6] shown in the Figure 3. In case of a full Snake the total spin rotation angle φ=π and T_x–matrix becomes the unity matrix, while T_y becomes minus unity matrix.

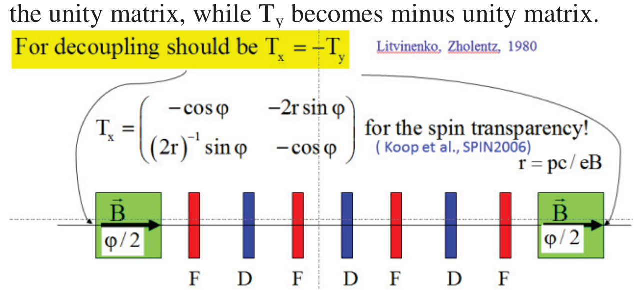

Figure 3: Spin transparent rotator optics scheme for the solenoid partial Snake.

MINIMIZATION OF SPIN TUNE CHROMATICITY

In a flat ring without snakes the spin tune chromaticity equals just to the tune ν_0 :

$$\gamma\frac{\partial \nu}{\partial \gamma} = \nu_0 = 180 \qquad \text{for} \quad \text{E=80 GeV}$$

With a single snake it becomes very small:

$$\left|\gamma\frac{\partial \nu}{\partial \gamma}\right| \le \frac{1}{2}\ .$$

With N-odd equally spaced snakes it may become N times larger. Alternation of a sign of the longitudinal field will make spin tune chromaticity again less than ½.

With such a small spin tune chromaticity the synchrotron satellites of intrinsic and integer spin resonances will disappear. This is very profitable for the

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acceleration of polarized beams to super-high energies [7, 8].

CONCLUSION

Use of Siberian Snakes for the acceleration of a polarized beam in a synchrotron is an obvious tool to solve such a difficult task. Three snakes (odd number) will ensure preservation of the polarization in a booster synchrotron of FCC-ee complex up to 80 GeV.

Spin tracking simulations should validate this statement and provide the solid basis for the choice of the number of snakes needed to solve a task.

Remark: the radiative diffusion effects need to be incorporated into the tracking code!

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