Spin Transparent Siberian Snake And Spin Rotator With Solenoids

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Spin dynamics in an accelerator

Spin precession in electro-magnetic field is given by the equation [1]

\[ \dot{\theta} = \frac{e}{m} \mathbf{A} \times \mathbf{P} \]

where \( e \) and \( m \) are normal and anomalous parts of gyromagnetic ratio correspondingly. Semi-classical Hamiltonian of orbit and spin motion can be written in the following way [2]

\[ H = \frac{1}{2} p^2 + V(r) + \mathbf{s} \times \mathbf{A} \]

Orbital motion does not depend on spin but determine fields that influence on spin. \( \mathbf{A} \) - Spin motion can be divided into two parts, by the following way, where \( \tilde{P} \) is precession on the ideal (reference) orbit, \( \mathbf{S} \) is a small imperfection due to betatron/synchrotron motion and closed orbit errors.

\[ \dot{\tilde{P}} = \frac{e}{m} \mathbf{A} \times \mathbf{P} \]

Spin transparency condition

Spin transparency is mostly actual for electrons and much less for protons. For electrons the synchrotron radiation it is caused by quantum fluctuations of electron magnetic moment, \( \Delta \gamma \), and corresponding behavior of a spin vector. Here \( \Delta \gamma / \gamma = \frac{e}{m} \mathbf{A} \times \mathbf{P} \)

To deliver spin longitudinal into the IP we need to install two spin rotators, one for each beam, and then it is bent by 180°. The right and left quadrupoles have to be rotated by opposite angles. The special scheme of the focusing structure was found, that contains only regular quadrupoles inside the spin-transparent sections: one for the beams collisions and other for a technical experimental area (on 12 o'clock). It is considered to consist of identical solenoids spaced by some optical structure in between. V.Litvinenko et al. in Ref.1 considered this problem and proposed an unique solution which is used in RHIC project.

Spin rotators in e-RHC project

In the Brookhaven National Laboratory (BNL) experiments at new collider RHIC have successfully started with both spin and polarized proton-antiproton beams. To understand the theoretical and experimental capability of the RHIC complex, different schemes of colliders and storage rings are considered. This kind of research continue until the first commissioning experiments in polarized DIS. In the suggestion of the project the electron ring with the energy 5-10 GeV will be construct mainly outside the RHIC tunnel and will have the circumference of 4/15 of the RHIC orbit.ォ Ou can take into account that the horizontal and vertical planes for the RHIC tunnel have to be equal to zero.

\[ \mathbf{H} \]

Spin transparent of partial waves and spin rotators.

Spin transparency is mostly actual for electrons and much less for protons. For electrons the synchrotron radiation it is caused by quantum fluctuations of electron magnetic moment, \( \Delta \gamma \), and corresponding behavior of a spin vector. Here \( \Delta \gamma / \gamma = \frac{e}{m} \mathbf{A} \times \mathbf{P} \). Where \( s \) is the spin tune, \( \Delta \tau = \frac{2\pi}{\gamma} f \) is the fraction of an electron magnetic moment, \( \eta \), the dimensionless bending or solenoidal fields, \( 0 \leq \eta \leq 1 \). The energy deviation. All orbit variables here also are dimensionless and differentiation is over the orbit in the time. We are interested to calculate the contribution of the betatron oscillations in the integral of the spin perturbation losses over the whole of the spin rotator location.

Spin rotator layout

The special scheme of the focusing structure was found, that contains only regular quadrupoles inside the spin-transparent sections: one for the beams collisions and other for a technical experimental area. At first, spin is rotated by a solenoid field to horizontal plane and then by low field dipoles (usually using final focus quadrupole magnets) exactly at the location of the horizontal \( \Delta \gamma / \gamma \) = const. Reduction of the spin motion will be found for both options of the IP layout.

Partial-Siberian Snake in the project of a Polarized Proton-Antiproton Collider at GSI.

A polarized proton-antiproton scattering facility will be considered as a possible part of the Facility for Antiproton and Ion Research (FAIR) at GSI in Darmstadt, Germany. We investigate the spin dependence on the parametric structure of the colliders. The center-of-mass energy of proton-antiproton collisions will be 30 GeV and luminosity of proton-antiproton colliding beams are 10^31 cm^-2 sec^-1.

The collider features two IP regions that are organized in two parallel long straights for the acceleration of both different experiments that can be run alternatively. One consists of the FAIR-ring and the other serves for Spin Equipment with Antiprotons (SEAP). In the opposite to the interaction region long straight proton and antiproton beams are electrostatically separated and then directed through different solenoids of the electron cooler. Simultaneously these solenoids serve for the spin control being a part of the Siberian Snake.

The cooler’s electron beam being accelerated to 8 MeV will be used for cooling of both p and p̅ beams in the opposite to the interaction region long straight proton and antiproton beams will be directed into other solenoid for second beam cooling. After passage through the second solenoid the electron beam returns back, to the acceleration region for de-excitation and energy recovery.

The cooler solenoid has the length 50 cm and magnetic field \( B = 0.7 \) T. One constrain of the e-cooling device is its delicate tuning, which demands to keep the magnetic field unchanged even while tuning.

On the other hand the field integral of the solenoid gives a big enough spin rotation angle. Adding four more solenoids it is possible to construct a full Siberian snake (\( 180°/\pi \approx 57° \)) for the top energy.

Compensating solenoids and super quadrupoles together with the solenoid for Electron cooling form the structure of the Siberian Snake. In order to compensate the coupling mismatch with these solenoids (cooling one) with other machine optics a number of skew quadrupoles are needed. Transformation matrix for the vertical motion is made equivalent to a drift space matrix with a length \( \lambda / 2 \). The total tune advance for vertical oscillations is equal to \( \Delta \nu / \lambda = 0.7 \), while for horizontal oscillations we have \( \Delta \nu / \lambda = 0.7 \).

In the horizontal plane the transformation matrix is minus matrix of a drift.

To compensate coupling from solenoids all quads should be rotated by the angle \( \Delta \nu / \lambda \).

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For intermediate energies of electrons and protons it happens that the Siberian snake and spin rotator can be constructed to use solenoid fields. Strong coupling caused by the solenoids is suppressed by a number of skew and normal quadruple magnets. More complicate problem of the spin transparency of such devices also can be solved. This paper gives two examples: spin rotator for electron ring in the eRHIC project and Siberian snake for proton (antiproton) storage ring HESR, which cover whole machines working energy region.

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