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Semi-step tuning and spin state estimation in neutron polarimetry

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Abstract

3D neutron polarimetric experiments require full control over the spatial orientation of the polarization vector prior to and after its interaction with the specimen and hence precise tuning of DC spin turn coil systems. An efficient algorithm was conceived which optimizes the two coil currents of a spin rotating device iteratively.

Keywords: Neutron depolarization; Larmor precession; Polarization analysis

Neutron spin polarimetry is a key technique both for solid-state physical applications, as e.g. three-dimensional neutron depolarization (3D-ND) [1], and fundamental physics [2]. It requires full control over the spatial orientation of the neutron polarization vector $\boldsymbol{P}$ along its trajectory through the interaction region. This can be achieved by cautious current tuning of dedicated spin turn devices, usually consisting of two coupled DC-coils. Hereafter, a new algorithm for the simultaneous optimization of the involved coil currents is presented.

We start from the equation of motion $\mathrm{d}\boldsymbol{P}/\mathrm{d}t = \boldsymbol{P} \times \gamma \boldsymbol{B}$ of the polarization vector in a magnetic field $\boldsymbol{B}$, with $\gamma = -1.833 \times 10^8$ rad/Ts the gyromagnetic ratio. The currents (that is, the magnetic fields) in a spin-turning coil system therefore determine the extent $\boldsymbol{P}$ precedes on its Larmor cone, and as to realize all combinations of incident and final polarizations, neutron polarimeters clearly need two such devices. Further, in polarimetry all results are quantified by quotients of intensities, e.g. the so-called flip ratios $R_{ij} = I^+_{ij}/I^-_{ij}$, $i,j = x, y, z$, where i and j give the spatial directions of the polarization vector upon entering or exiting the sample, respectively, and I^- (I^+) denotes the intensity measured with an inserted spin-flip device switched on (off).

For instance, we focus on R_{xj}, i.e. all flip ratios which require the incoming $\hat{z}$-aligned vector of polarization to be rotated into $\hat{x}$ direction (see Fig. 1). This rotation $\hat{z} \to \hat{x}$ can be caused by a magnetic field $\boldsymbol{B}_{xz}$ in the xz-plane produced by a spin turner consisting of two coils wound crosswise upon each other. The alignment of $\boldsymbol{P}_0$ along $\hat{x}$ implies $P_{0y} = P_{0z} = 0$ or, equivalently, $R_{xy} = 1$ and $R_{xz} = 1$. Upon tuning both coil currents one has to meet these conditions *simultaneously*, but measuring R_{xy} (R_{xz}) can tell only whether $\boldsymbol{P}$ lies *inside* the xy-plane (xz-plane), but not *where*.

Employing the solution to the given equation of motion for $\boldsymbol{P}$ one can transfer the upper conditions onto the coil currents I_x, I_z causing the x and z components of $\boldsymbol{B}_{xz}$, respectively. If κ is the Larmor angle per unit current (given by coil geometry and neutron wavelength) $R_{xy} = 1$ ($P_y = 0$) corresponds to $I_x^2 + I_z^2 = (\kappa/\pi)^2$, while $R_{xz} = 1$ ($P_z = 0$) is equivalent to $I_z^2/I_x^2 + \cos\kappa\sqrt{I_x^2 + I_z^2} = 0$ or $\cot^2\varphi + \cos\kappa I = 0$ with polar coordinates $\tan\varphi = I_x/I_z$ and $I = \sqrt{I_x^2 + I_z^2}$. Fig. 2 shows these relations graphically: $R_{xy} = 1$ is the quarter of a circle, $R_{xz} = 1$ is a higher-order implicit curve. They intersect at right angles in exactly one point (the simultaneous solution searched for) that for the herein assumed ideality coincides with the intersection of $R_{xy} = 1$ and the first median ($I_x = I_z$), which itself is limit and tangent to $R_{xz} = 1$ in the point of intersection. The latter property arises from the fact that no Larmor rotation of $\boldsymbol{P}_i$ about

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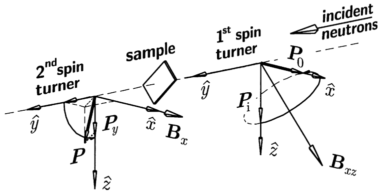

Fig. 1. Polarimetry at the example R_{xy}: the incident polarization $\boldsymbol{P}_i$ is transformed by a spin turner into $\boldsymbol{P}_0 \| \hat{x}$. The polarization $\boldsymbol{P}$ behind the sample (interaction region) is determined by rotating its respective component (here P_y) into $\hat{z}$, the spin analyzer's preferred axis, by means of a second spin turner.

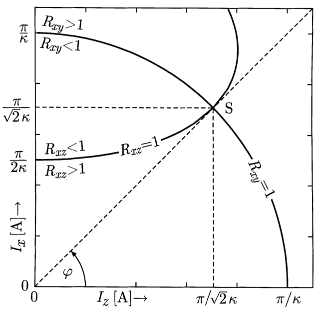

Fig. 2. $R_{xy} = 1$ and $R_{xz} = 1$ curves in the I_z–I_x-plane, the intersection point S is the searched-for solution.

an axis tilted by less than 45° with respect to $\hat{z}$ can ever lead to $P_{0z} = 0$, due to the insufficient opening angle of the precession cone.

As spin-turners in reality are always influenced by magnetic strayfields, the currents cannot simply be adjusted according to their theoretical values, moreover they have to be tuned towards an optimum. Mere alternate optimization of either flip-ratio R_{xy} or R_{xz} leads to

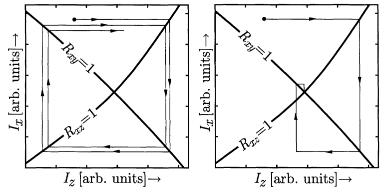

Fig. 3. Alternate optimization in full steps (left) is tedious and unreliable, whereas semi-step tuning (right) always converges rapidly.

no success (Fig. 3). The approach towards the intersection point is obviously quite slow. To improve the convergence rate, we conceived *semi-step tuning* (SST): apart from the first I_z optimization all, let us say, I_z adjustments are executed over only half the optimization distance ($R_{xz} = 1$), whereas the I_x paths are taken fully.

SST is stable and rapidly converging without featuring error accumulation, its results are always as precise as the last optimization towards $R_{xy} = 1$ or $R_{xz} = 1$ was. It is particularly suited for automatized execution in a computer-controlled experiment, as has recently been demonstrated at the ND facility at the TRIGA reactor Vienna. There, experiments are currently prepared to verify the concept of maximum likelihood spin state reconstruction, which heavily relies upon precise control of neutron polarization. As space is limited here, we refer to a forthcoming paper for details [3].

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References

[1] M.Th. Rekveldt, Z. Physik 259 (1973) 391.
[2] Y. Hasegawa, G. Badurek, Phys. Rev. A 59 (1999) 4614.
[3] Z. Hradil et al., Phys. Rev. A (2000), submitted.