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ScienceDirect
Physica B 385–386 (2006) 1138–1141
PHYSICA B
www.elsevier.com/locate/physb

A tiny neutron spin filter

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Abstract

We have designed and demonstrated a very compact neutron spin filter (NSF) based on polarized gaseous ^{3}He. It is 5 cm in diameter and 20 cm in length; the total volume is only 400 cc. It also features a fast spin flip capability. The ^{3}He spin, corresponding to that of neutrons, can be reversed by adiabatic fast passage (AFP) in less than a second. The AFP spin flip provides NMR signals for polarization monitoring and leaves no magnetic field change before and after the spin flip, which is essential in polarized neutron scattering experiments to cancel systematic uncertainties. In the article, we describe the design and performance of this tiny NSF.

PACS: 61.12.−q; 75.25.+z; 29.25.Pj; 29.27.Hj

Keywords: ^{3}He polarization; Neutron spin filter; Polarized neutron; Neutron scattering; Adiabatic fast passage (AFP); Spallation neutron source

1. Introduction

The polarized ^{3}He neutron spin filter (NSF) will play an important role at the next generation high-intensity pulsed-neutron sources as well as at high-power reactor sources. The neutron capture cross-section of ^{3}He nuclei, which is inversely proportional to the square root of neutron energy, enables one to polarize neutrons over a broad energy range. Gaseous ^{3}He makes polarization analysis possible for scattered neutrons over a large solid angle. Unlike supermirror polarizers, the ^{3}He NSF can be used up to epithermal energies. On the other hand, many neutron-scattering instruments have limited space for such devices, especially at spallation neutron sources where spectrometers are inside thick radiation shieldings. In addition, polarized neutron-scattering measurements often require spin flips of the initial neutrons and/or the scattered neutrons. To fulfill these conflicting demands, we have developed a very compact NSF based on polarized gaseous ^{3}He with a fast spin flip capability.

A photograph of our tiny NSF is presented as Fig. 1. The size is 5 cm in diameter and 20 cm in length. The total volume becomes only 400 cc. Another important feature of this tiny NSF is a fast spin flip capability. The ^{3}He spin can be flipped by adiabatic fast passage (AFP) [1] with very little polarization losses.

We have already reported another compact NSF [2], the size of which was 12 cm in diameter and 50 cm in length, and was still too large to fit in some spectrometers. The new tiny NSF is 1/15 of the previous NSF in volume and can easily be installed in many spectrometers as neutron polarizers as well as neutron spin analyzers.

2. Design

The tiny NSF was designed to polarize thermal neutrons with a beam aperture of 20 mm in diameter. Hence a cylindrical cell with an inner diameter of 24 mm and an inner thickness of 50 mm was filled with ^{3}He at 3 atm [3], which was optimized for thermal neutron polarization.

It is necessary to provide a uniform magnetic field for polarized ^{3}He since field gradients contribute spin relaxation [4]. A uniform field was realized with a solenoid and two compensation coils at both solenoid edges. The solenoid was wound on a cylindrical bobbin with a diameter of 50 mm and a length of 200 mm. The compensation coils were wound on the solenoid. The number of turns of the compensation coils was determined by magnetic-field calculations to minimize the field

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doi:10.1016/j.physb.2006.05.392

gradients at the ^{3}He cell that was placed at the coil center, and so that all the coils were operated by one power supply. Each coil was wound with ϕ 0.34 mm enameled copper wire in two layers to reduce current as well as to minimize magnetic field interference produced by separated lead wires because an electric current of only 1 cm makes unacceptable field gradients. Fig. 2 shows the transverse field gradients $(\partial B_T/\partial T)/B_Z$ calculated for the coils. Here, B_Z and B_T are the magnetic field component along the solenoid axis (Z) and in the transverse direction (T), respectively. The ^{3}He cell sits inside the transverse field gradient being less than 0.0002 cm^{-1} in magnitude, which corresponds to the spin relaxation time by the field gradient to be over 4000 h for ^{3}He at 3 atm [4].

RF magnetic field for AFP is provided by two loop coils arranged inside the solenoid bobbin as illustrated in Fig. 3. The four linear sections of the loops are in parallel to the solenoid axis and responsible for producing a uniform RF magnetic field at the ^{3}He cell. They are 20 mm apart in the X direction, and 38 mm in the Y direction. This RF coil geometry was optimized by static magnetic field calculations to maximize the uniformity. Fig. 4 shows the magnetic field calculations for a 3D model of the RF coils that includes the arc sections.

The calculations show static magnetic field produced by the RF loop coils varies only 10% inside the ^{3}He cell, and it should satisfy the adiabatic condition for AFP

$$\frac{1}{H_1}\frac{\mathrm{d}H_0}{\mathrm{d}t} \ll \gamma H_1 \qquad (1)$$

where γ is the gyromagnetic ratio of the ^{3}He nucleus, H_1 a rotational component of the RF magnetic field, and $\mathrm{d}H_0/\mathrm{d}t$ the sweep speed of the spin-holding field [1]. The transverse gradient of the RF magnetic field may cause depolarization of ^{3}He nuclei. To avoid this, the RF field was kept off except only when it was necessary.

The actual RF field may differ from the static calculations because of the existence of conductive materials near the RF coils such as the solenoid and the compensation coils. However, the effect of such perturbations was found to be negligible for AFP as shown in the next section.

Another small circular loop coil was placed, perpendicular to both solenoid and RF loop coils, underneath the ^{3}He cell as a pick-up coil for AFP-NMR.

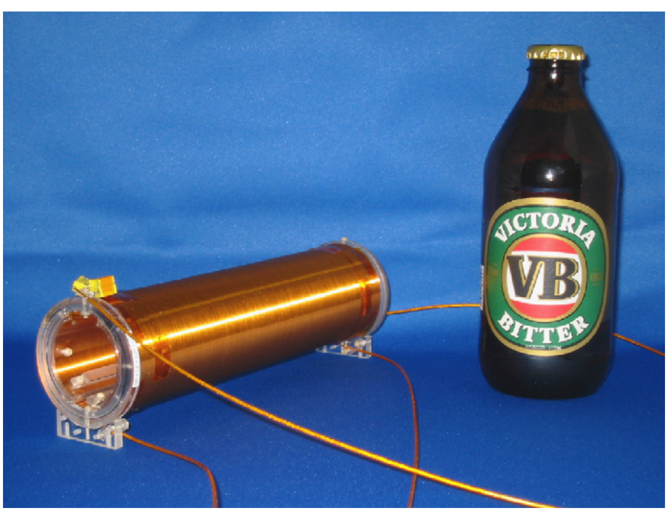

Fig. 1. The tiny NSF along with a 375 ml bottle for scale.

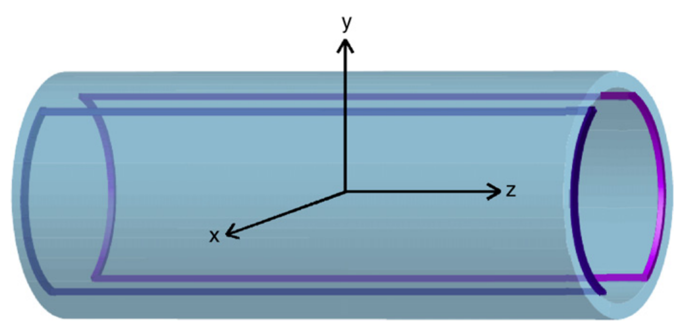

Fig. 3. The RF loop coils inside the solenoid bobbin. The two RF coils are separated by 20 mm at the linear sections, and the linear sections of each coil are 38 mm apart.

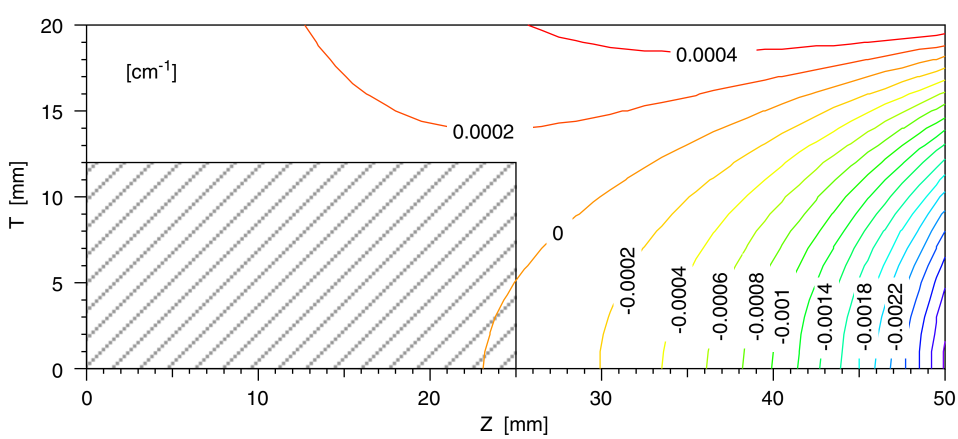

Fig. 2. Calculations of transverse field gradient for the solenoid with the compensation coils plotted for the T–Z plain, where Z corresponds to the solenoid axis, and T is the transverse distance from the solenoid axis. The center of the coils is at ($T = 0$, $Z = 0$). The shadowed area corresponds to the ^{3}He cell.