An In-situ He-3 Polarizer, a Noble Hybrid RF Spin Flipper, and a Two-coil Spin Flipper Deigned for Polarized Neutron Instruments

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1. Introduction

For possible implementations of a He-3 based neutron polarizer at the neutron beam lines of HANARO (High-Flux Advanced Neutron Research Reactor), we are developing a He-3 polarizer, a RF spin flipper, and a two-coil spin flipper. A compact in-situ He-3 polarizer was developed to maintain a constant neutron polarization in the neutron beam line during experiments. To have better control of neutron spins under stray magnetic field environments, a noble hybrid RF spin flipper with a high gradient magnetic field and a magnetic field compensation capability has been designed based on DC coils and permanent magnets. In addition, a compact two-coil spin flipper, which can be combined effectively with a He-3 polarizer, has been designed for uses with the small sizes of the neutron beam. The detailed characteristics of the in-situ He-3 polarizer and the design criteria of the spin flippers are presented.

2. Methods and Results

In this section the detailed geometries and the related magnetic field profiles of the neutron polarization-optics including the He-3 polarizer, the RF flipper, and the two-coil flipper are described in detail.

2.1 In-situ He-3 Polarizer

The developed in-situ He-3 polarizer system is shown Fig. 1. The main body of the He-3 polarizer consists of a compact holding solenoid, a He-3 cell, NMR coils, a hot air supplier, laser beam transport optics, and guiding coils. The length of the polarizer including two DC guide coils is 360 mm, and the diameter of the cylindrical magnetic shield is 220 mm.

The holding solenoid coil has a relatively short length of 280 mm. However, by employing end compensation coils at both ends and a negative compensation coil in the middle, the short solenoid could generate a magnetic field of more than 20 G with a uniformity of $\Delta B/B = 2.0\times10^{-4}$ cm^{-1} in the axial direction.

Fig. 1 A compact in-situ He-3 polarizer system developed at KAERI.

Depending on the neutron energies of neutron beam lines, a He-3 cell of the He-3 polarizer needs to be optimized to achieve a higher neutron polarization. As shown in Fig. 2, various He-3 cells were manufactured at KAERI by using a GE-180 glass. He-3 cells with a diameter to 100 mm and a filling gas pressure to several bars could be delivered routinely.

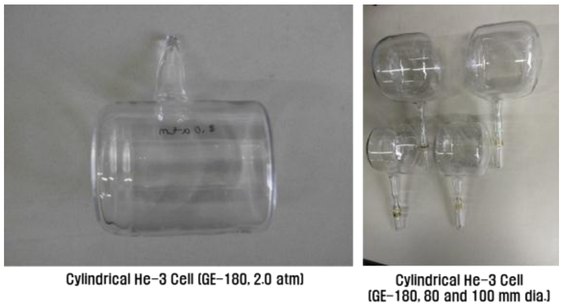

Fig. 2 Cylindrical He-3 cells manufactured at KAERI.

Figure 3 shows the NMR signal measured for the in-situ He-3 polarizer, which has a He-3 gas pressure of 1 atm. The polarization ratio of the He-3 polarizer depends strongly on a cell size, a cell temperature, a gas pressure, a mixed ratio of Rb and Cs metal vapors, a pumping-laser output power, and a laser linewidth. A He-3 gas polarization of more than 70% could be supplied by using the He-3 cells with a larger diameter close to 100 mm.

Fig. 3 A NMR signal measured for the in-situ He-3 polarizer.

2.2 Hybrid RF Spin Flipper

A noble hybrid RF spin flipper has been designed as shown in Fig. 4 by utilizing both DC coils and permanent magnets. In combined with two DC coils, four permanent magnets (NdFeB, $20\times80\times10mm^3$) inserted in the side mild steel plates magnetize the lower and the upper iron steel plates and generate a vertical magnetic field with a field gradient in the axial direction. In comparison to RF flippers, which only employ DC coils or permanent magnets, our RF flipper is superior in providing an accurate high magnetic field gradient in the middle of the RF coil. For example, the varied field gradient caused by various sample and stray field environments can be compensated by adjusting the DC coil current. Furthermore, the high magnetic field gradient can be generated at a low DC current and with a small wire turns of the DC coil, which is advantageous in operating the RF flipper in vacuum due to a low heat generation of the DC coil.

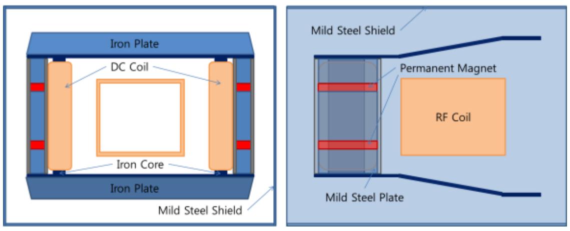

Fig. 4 Schematic diagram of the noble hybrid RF spin flipper utilizing DC coils and permanent magnets: front view (left) and side view (right).

As shown in Fig. 5, the axial gradient magnetic field of the RF coil is calculated in the direction of neutron beam propagation with a DC coil current of 2 A and a coil turns of 400. Near the center of the RF coil, the magnetic field, B_y reached 43.5 G, and the magnetic field gradient was approximately 1.1 G/cm within the RF coil. The high magnetic field and the field gradient are sufficient to suppress the effects of external stray magnetic fields.

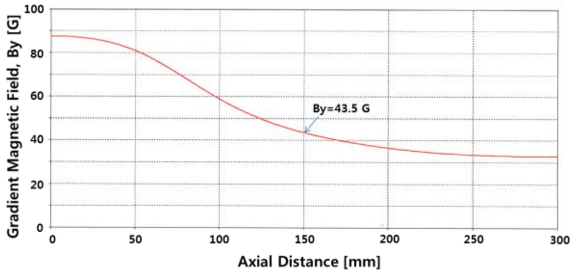

Fig. 5 An axial field gradient calculated along the direction of neutron beam propagation. DC coil current I_{dc} = 2 A, coil turns N = 400.

2.3 Two-coil Spin Flipper

A two-coil spin flipper, which is often called a Drabkin flipper, has been designed to use as one of flipper options. Even though a two-coil flipper with a large effective cross-section can be designed with a long working distance, a two coil flipper is effective for uses with the neutron beam with a small cross-section. In addition, the magnetic field profile of a two-coil spin flipper well matches with that of a He-3 polarizer. In this regard, a compact two-coil flipper in combined with a He-3 polarizer could be utilized for the polarized neutron diffractometer with an incident neutron-beam-size less than 30 mm.

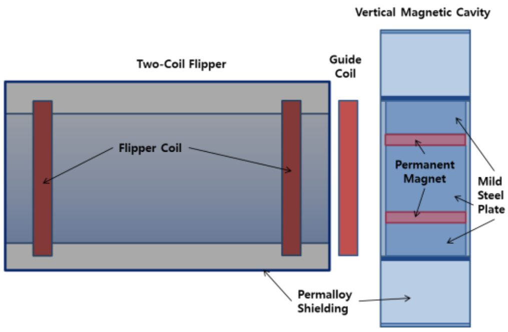

Fig. 6 Layout of the two-coil spin flipper employed with a guide coil and a vertical magnetic cavity.

For such applications, as shown in Fig. 6 we designed a two-coil flipper, a guide coil, and a vertical magnetic cavity. Their magnetic field, **B** was calculated in the direction of neutron beam propagation as shown in Fig 7. In this calculation, each coil of the two-coil flipper has the same current of 1 A and the same coil turns of 144. The guide coil is assumed to have the same current magnitude, current direction, and wire turns with that of the second coil of the two coil flipper.

For the two coil flipper, the magnetic field, B_z was canceled near the middle of the flipper due to the opposite current sign between two coils. This leads to a non-adiabatic spin flipping of neutron beams during propagation through the middle of the flipper. At a distance of approximately 400 mm, the field, B_z of the guide coil is diminished to near zero and the field, B_y of the vertical cavity remains only at the approximately 30 G. The smooth directional rotation of the magnetic field from z- to y- axis enables the neutron spins to follow the direction of the rotational magnetic field adiabatically. Note that the high magnetic flux density, 30 G is sufficient for the flipper system to be applied under strong stray magnetic field environments. If the current sign of the second coil and the guide coil is reversed together, the direction of neutron spins remains same with that of the magnetic field in the second half of the two coil flipper.

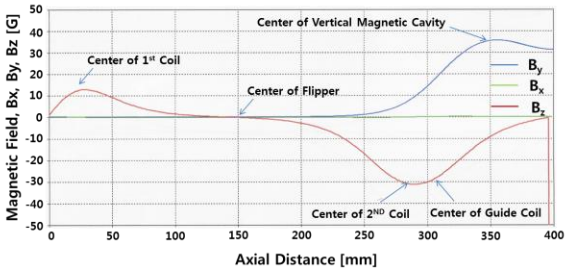

Fig. 7 An axial magnetic field of the two coil flipper calculated along the direction of neutron beam propagation. Coil current I = 1 A, coil turns N = 144.

3. Conclusions

The developed compact in-situ He-3 polarizer, the hybrid RF flipper, and the two-coil spin flipper system can be a useful option for implementing a polarization analysis capability in various polarized neutron instruments.[1-6] With minor modifications for optimization, the developed neutron polarization optics could be applied for a polarized neutron reflectometer, a polarized SANS, a polarized neutron imaging, and a polarized neutron diffractometer.

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