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A proposal of neutron spin echo spectrometers at the new pulsed neutron source in Japan

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Abstract

The neutron spin echo (NSE) spectroscopy is a unique method which can measure inelastic / quasi-elastic scattering with the highest energy resolution of 10^{-5} without losing neutron intensity and it supplies the intermediate structure factor $I(Q,t)$ which is better to understand relaxation phenomena. Therefore, NSE spectrometer is an eligible candidate to construct at the new pulsed neutron source in Japan. We have considered some technical problems to develop an NSE spectrometer at pulsed sources, and reached a conclusion that all the problems could essentially be solved.

1. Introduction

The NSE method was first proposed by Mezei in 1970's. [1] The principal advantage of this method is that a resolution of energy change on scattering is decoupled with a wavelength resolution because of using an echo of a Larmor spin precession in an external magnetic field to measure a neutron wavelength difference of the scattered neutrons. Therefore, NSE can observe inelastic and quasi-elastic scattering at the highest energy resolution of 10^{-5} without losing neutron intensity.

Another advantage of the NSE is that it gives an intermediate correlation function $I(Q,t)$ instead of $S(Q,\omega)$. Of course, these two are complementary as "both sides of a coin". The $I(Q,t)$ has rich information to know relaxation behaviors while the $S(Q,\omega)$ is better to clarify excitations. However, there is no other direct method to measure $I(Q,t)$ in this Q ($0.01 < Q < 1$ Å^{-1}) and t ($0.01 < t < 100$ ns) range, so that the NSE is a unique method comparing with other inelastic / quasi-elastic neutron scattering techniques. One of important results obtained by means of NSE is the works done by Richter *et al.* [2] They investigated the dynamics of polymers and proved the reputation motion of polymer chains which was predicted by de Gennes. Therefore, it is believed that an NSE spectrometer is an eligible candidate to be constructed at next generation spallation neutron sources.

The first NSE spectrometer, IN11, was constructed at ILL and has shown the feasibility and usefulness of this method. Thus some other spectrometers have been constructed at LLB in France, FZ Jülich in Germany, JAERI in Japan, NIST in USA, and so on. However, until now, all the existing NSE spectrometers are installed only at steady neutron sources and not at spallation sources, because there are some technical difficulties to operate it for white neutron beam.

In this report, we have considered the possibility of constructing NSE spectrometers and estimated expected performances at the new pulsed spallation neutron source in Japan. It is shown that all the difficulties will be solved, while some other technical developments especially on spin flippers are more useful. For our first R&D works, new type of π-flipper was tested.

2. Possibility of an NSE spectrometer at spallation neutron sources

The possibility of the application of NSE on pulsed neutron sources was already discussed by Mezei in 1979. [3] He showed that the NSE technique could be readily adapted to a pulsed neutron source. It offers a substantial gain in neutron intensity because it uses a large incoming wavelength band simultaneously.

Recently, the time-of-flight spin echo was first operated at IN15 at ILL. [4] The usual velocity selector was replaced by four choppers which selected a wavelength band and avoids frame-overlap. The TOF enabled only the use of a wide range of wavelength, the energy analysis was made by the NSE technique. Once the symmetry condition of the magnetic field integral before and after the scattering is satisfied, the spin echo signal could be obtained independently of the wavelength. On the other hand, the three flippers (π/2 - π - π/2) at any time have different wavelength neutrons just crossing them, so that the current of the flippers must be controlled depending on time, i. e., the wavelength. This was achieved by programmable power supplies which sweeped their current with synchronizing to a trigger from the choppers. The system worked well and they proved the feasibility of the NSE technique on a pulsed source. However, they also noted that the optimization of at least 12 other correction currents was necessary.

3. Development of spin flippers with steady current

New type π and π/2 flippers operated with steady current have been designed by one of the authors (T.T). The π flipper consists of a compact modified current sheet and Helmholtz coils. The current sheet produces magnetic fields $\boldsymbol{B}_S$ parallel to the sheet surface without magnetic fields perpendicular to the sheet surface at the surface of the sheet for the neutron beam cross section. The correction field from Helmholtz coils $\boldsymbol{B}_C$ cancel out the perpendicular component of the magnetic field from the precession coils $\boldsymbol{B}_0$ at the current sheet. As shown in Fig. 1, the direction of the magnetic field $\boldsymbol{B} = \boldsymbol{B}_S + \boldsymbol{B}_0 + \boldsymbol{B}_C$ in which neutrons travel rotates slowly and the neutron spin follows the change of $\boldsymbol{B}$ adiabatically outside the current sheet. Crossing the current sheet, the direction of $\boldsymbol{B}$ reverses suddenly without

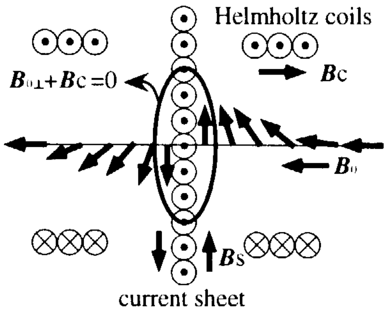

Fig. 1. Direction of the magnetic field $\boldsymbol{B} = \boldsymbol{B}_S + \boldsymbol{B}_0 + \boldsymbol{B}_C$ in the π flipper with a modified current sheet and Helmholtz coils.

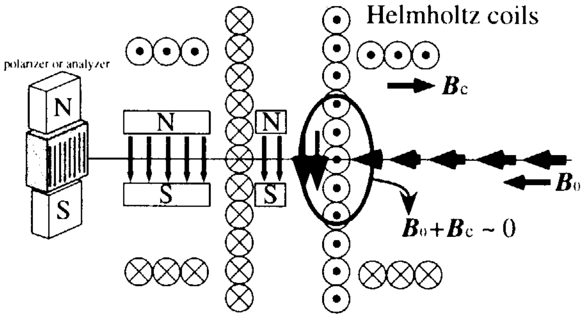

Fig. 2. Direction of the magnetic field $\boldsymbol{B} = \boldsymbol{B}_r + \boldsymbol{B}_0 + \boldsymbol{B}_C$ in the $\pi/2$ flipper with a rectangular coil and Helmholtz coils.

the change in the neutron spin direction. As a result, the above coil system operates as a π flipper without tuning independently of the neutron wavelength. The $\pi/2$ flipper consists of a rectangular coil and Helmholtz coils as shown in Fig. 2. The rectangular coil produces magnetic fields $\boldsymbol{B}_r$ perpendicular to the magnetic field from the precession coils $\boldsymbol{B}_0$. The correction field from Helmholtz coils $\boldsymbol{B}_C$ cancel out $\boldsymbol{B}_0$ at the right-side current sheet of the rectangular coil. Crossing the current sheet, the direction of the magnetic field $\boldsymbol{B} = \boldsymbol{B}_r + \boldsymbol{B}_0 + \boldsymbol{B}_C$ turns by $\pi/2$ suddenly without the change in the neutron spin direction. As a result, this coil system operates as a $\pi/2$ flipper without tuning independently of the neutron wavelength.

A performance test of the new-type π flipper with compact modified current sheet was carried out using ISSP-NSE at JAERI, Tokai Japan. Neutrons with the wavelength λ=7.14 Å (FWHM of its resolution $\Delta\lambda/\lambda$ = 18%) were used. The Mezei-type π flipper was replaced with a new-type one. As shown in Fig.3, the current sheet was wound with an Al-conductor wire of 1 mm in diameter and the current density per 1 mm width of the sheet is the followings;

I (A/mm) for $-25 \le z \le 25$ (mm),

$2I$ (A/mm) for $-50 \le z \le -25$ (mm) and $25 \le z \le 50$ (mm),

$3I$ (A/mm) for $-75 \le z \le -50$ (mm) and $50 \le z \le 75$ (mm),

$-6I$ (A/mm) for $-100 \le z \le -75$ (mm) and $75 \le z \le 100$ (mm),

where I is current of the Al-conductor wire. The performance of the new type π flipper was comparable to that of the Mezei-type. Figure 4 shows a example of the NSE signal profile observed using the new-type π flipper with the field integral D = 0.11Tm (Fourier time t = 7.5 ns), the beam cross section at the current sheet W = $20^w \times 40^h$ mm^2 and I = 1.24 A.

4. Estimation of NSE spectrometers at the new spallation source in Japan

Time averaged intensity of the new spallation source operated at 1MW is roughly estimated to be 1/4 of ILL. If we move the ISSP-NSE to the new source and run it with the monochromatized beam, its performance in the intensity will be 5 times at

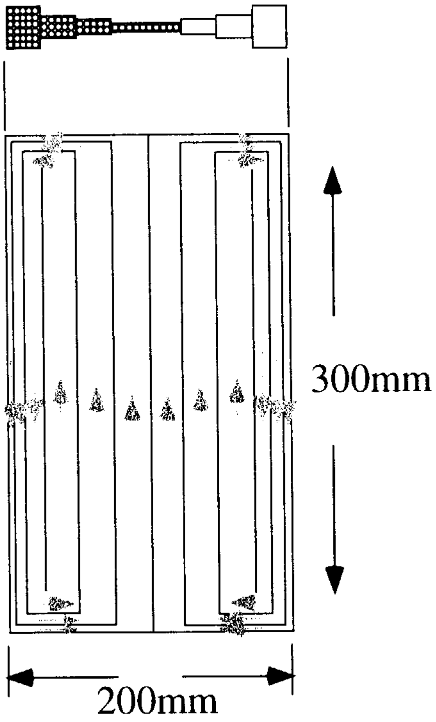

Fig. 3. Winding of the modified current sheet. Arrows indicate the direction of current and their length are proportional to the current density.

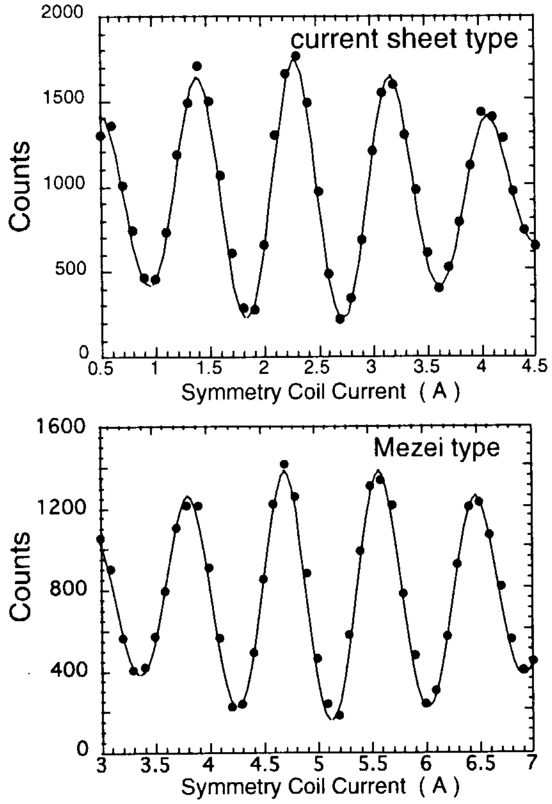

Fig. 4. Example of the NSE signal profile observed using the new type π flipper comparing with a similar result using a Mezei type π flipper.

C2-2 port of JRR-3M, because its present intensity is about 1/20 of IN11 at ILL. If we operate it at TOF mode, practical efficiency will be increased because a large range of wavelength distribution can be used and several points of $I(Q,t)$ are able to be measured simultaneously. Therefore , at the new spallation source in Japan, we can construct an NSE spectrometer of one order of magnitude better performance than the ISSP-NSE.

This type of NSE spectrometer has a disadvantage that it is easily influenced by a fluctuation of surrounding magnetic field. Thus 3 other possible methods of the NSE spectroscopy were also considered. (1) "Resonance spin echo", which uses radio frequency flippers to introduce phase difference among spin state. (2) "Mieze spin echo", which also uses rf-flippers and measures time beat at the focusing position. (3) Optical phase spin echo, in which multilayer spin splitters is utilized instead of Larmor precessing magnet. All of them are now under development and many problems have to be solved, however, they have advantages in their size and tolerance against the magnetic field fluctuation.

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