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Feasibility study on application of a magnetic neutron lens to SANS experiments

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Abstract

The neutron focusing effect of a superconducting sextupole magnet has been investigated using unpolarized and polarized cold neutrons. The feasibility on the application of the magnetic lens to small-angle neutron scattering experiments are discussed.

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Keywords: Magnetic neutron lens; Cold neutron; Spin flipper; Beam focusing; Sextupole magnet

1. Introduction

A sextupole magnetic field functions as an ideal focusing and defocusing lens for neutrons when the neutron has positive and negative spin polarity to the local field, respectively. So far, the neutron focusing effect of sextupole magnets has been investigated experimentally and numerically [1,2]. For practical use of the lens function of a sextupole magnet in neutron scattering experiments, a sextupole magnet with a sufficiently large aperture accompanied with strong focusing power is demanded. Recently, we have developed a superconducting sextupole magnet (SSM) with an aperture of 46.8 mm in diameter which generates the sextupole magnetic field $B = (G/2)r^2$ with $G = 12{,}800\ \mathrm{T/m^2}$, where r is the distance from the magnet axis [3].

Its neutron focusing effect has been investigated using unpolarized cold neutrons [4]. We have proposed to apply the sextupole magnet to small-angle neutron scattering experiments with focusing geometry (FSANS) to improve the q-resolution and/or measuring efficiency by focusing neutrons on the detector [5–7]. To get the advantage in the

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practical FSANS measurement over a conventional pinhole-geometry SANS experiment, it is necessary to employ a neutron focusing device with little scattering and absorption of the neutrons. The sextupole magnet is considered to be a suitable focusing device, because of its neutron focusing property which is free from the scattering and absorption of the neutrons. However, if neutrons with negative spin polarity are included in the incident beam, they are defocused by the sextupole magnet and, then raise the background level. Therefore, the incident beam should be well polarized in case of the FSANS experiment with the sextupole magnet. In this paper, we investigated the neutron focusing effect of the SSM using unpolarized and polarized neutrons, and discussed the feasibility of the SSM on the application to the FSANS experiments.

2. Experimental setup

The SSM has a 2-m-long sextupole coil which is composed of six saddle-shaped coils. There exists non-adiabatic regions where the neutron spin is flipped: (1) around the center axis of the magnet where the sextupole magnetic field is weak, (2) around both ends of the sextupole coil where the magnetic field distribution deviates from the sextupole magnetic field distribution. We then removed these non-adiabatic regions by applying a dipole field along the beam axis using solenoid coils equipped in the SSM. The detailed specifications of the SSM are described in Ref. [3]. The SSM was installed at the beamline C3-1-2-1 of JRR-3 in Japan Atomic Energy Research Institute (JAERI). The experimental setup is shown in Fig. 1. The neutrons are monochromatized by the mechanical velocity selector. The neutron wavelength is $\lambda = 13.44$ Å with $\Delta\lambda/\lambda = 0.177$. The polarizer is the FeSi magnetic supermirror. We used the transmitted neutrons through the polarizer, which have negative spin polarity. The spin polarization efficiency is 0.957 ± 0.035. The transmission of the polarized neutrons with $\lambda = 13.44$ Å through the polarizer is ~ 0.66. The spin flipper (SF) is a radio-frequency gradient spin flipper which was designed to be effective for the neutron beam with wavelengths longer than 4 Å and a beam size of 50 mm in diameter [8]. The neutrons with positive and negative spin polarity are incident in the SSM when the SF is on and off, respectively.

We measured 2D neutron intensity distribution using a neutron imaging plate (BAS-ND) with position resolution of 0.2 mm under several conditions as follows:

Case 1: SSM on, polarizer off: The incident beam to the SSM is unpolarized.

Case 2: SSM on, polarizer on, SF on: The incident beam to the SSM is polarized with positive spin polarity.

Case 3: SSM on, polarizer on, SF off: The incident beam to the SSM is polarized with negative spin polarity.

Case 4: SSM off, polarizer on: SSM is off.

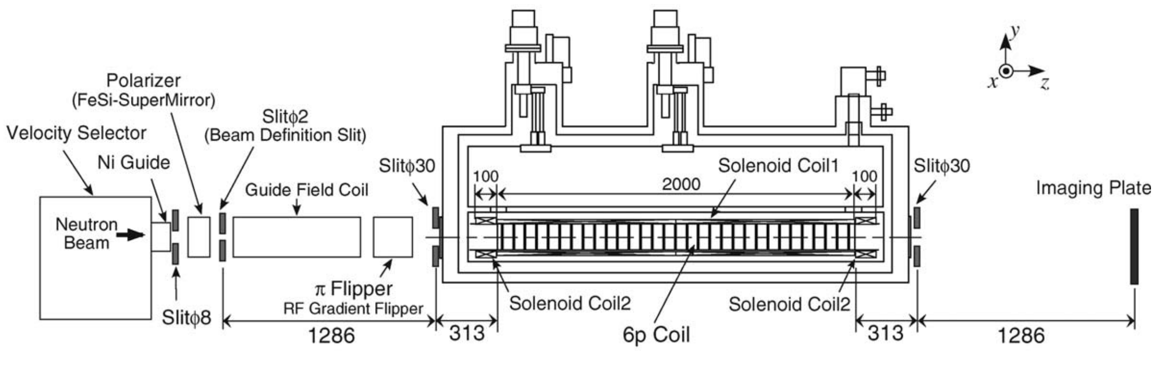

Fig. 1. Experimental setup.

Case 5: Beam shutter closed: The incident beam to the SSM is shut out for the background measurement.

Each measuring time is 11 h. When the SSM is on, current in the sextupole coil is $I_{\mathrm{ssm}} = 210$ A, which corresponds to the current to produce the magnetic field gradient of $G = 8235.6\ \mathrm{T/m^2}$. In this condition, the neutrons with positive spin polarity are focused on the detector (Fig. 1). When the SSM is off, $G = 0$ and the neutrons are not accelerated by the SSM. When the polarizer is on, solenoid coils are also excited to remove the non-adiabatic regions.

3. Experimental result and discussion

Fig. 2 shows the measured 2D intensity distributions. Comparing cases 1 and 4 (Figs. 2(a) and (d)), we can confirm that neutrons are focused on the detector by the SSM. The measured 2D intensity distribution of the focused neutrons showed a deformed pattern (Fig. 2(a)), resulting from the inhomogeneous incident beam distribution and the wavelength resolution because of the chromatic aberration of the SSM. In case 2, neutrons are focused with less background as

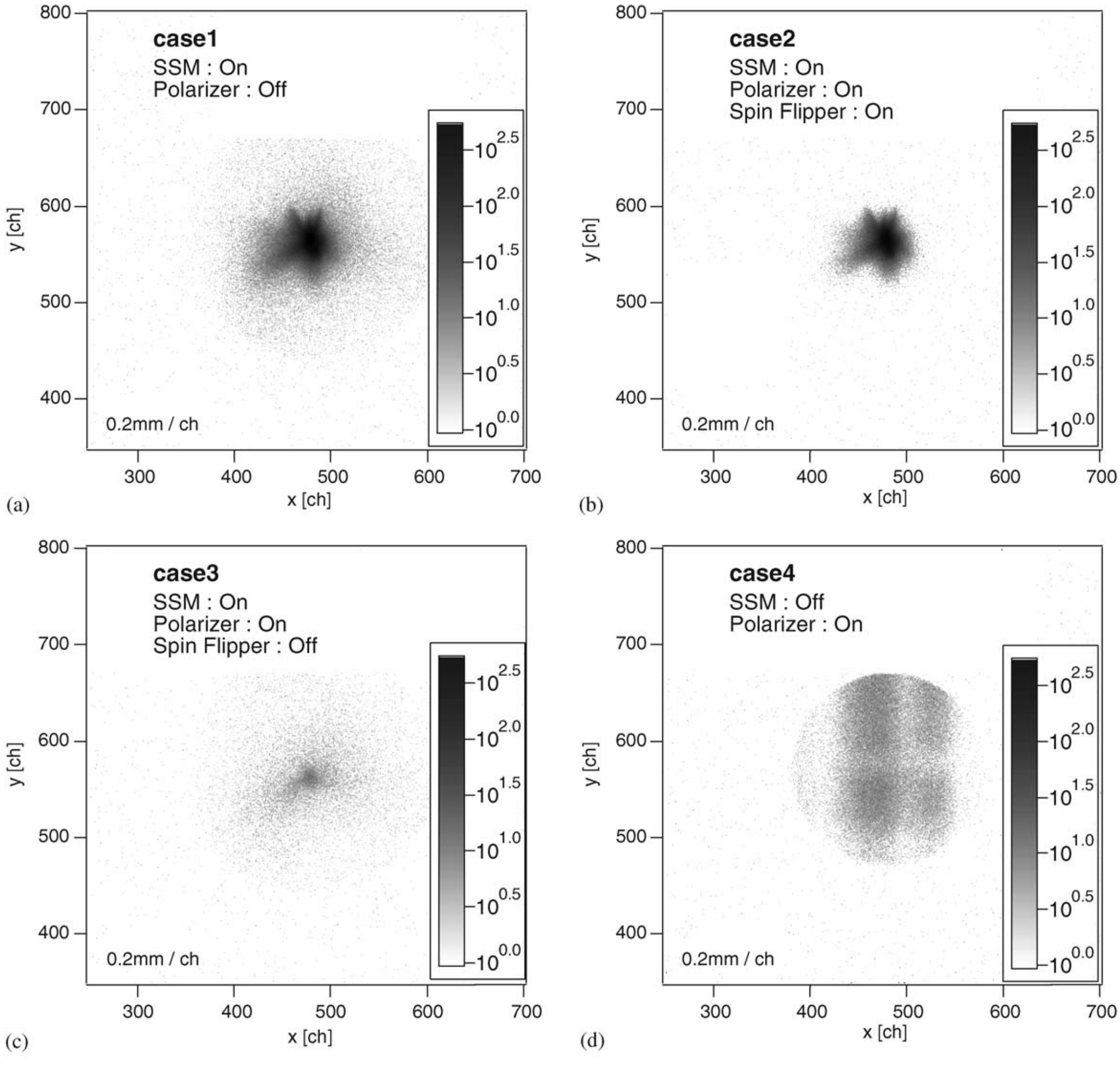

Fig. 2. 2D intensity distribution.

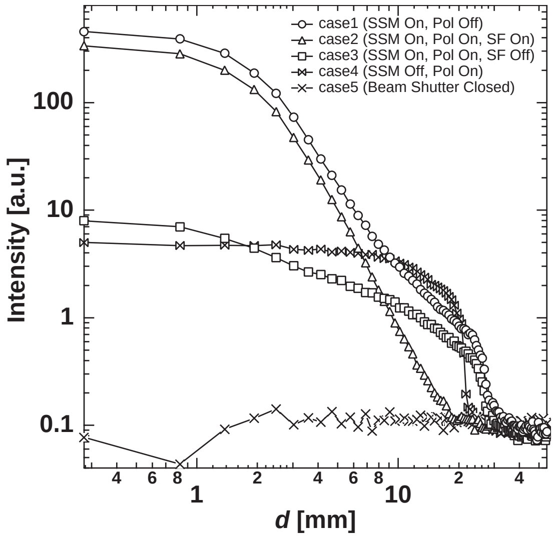

Fig. 3. Radially averaged intensity. d is the distance from the intensity peak position.

compared with case 1 (Fig. 2(b)). In case 3, we observed that a small number of neutrons were focused (Fig. 2(c)), which were considered to be the neutrons with positive spin polarity included in the incident beam of the SSM due to the imperfect spin polarization of the incident beam.

The radially averaged intensity is plotted as a function of d, where d is the distance from the peak position of the 2D intensity distributions (Fig. 3). In cases 1 and 3, a shoulder was observed around $d \sim 23$ mm, but not in case 2 (Fig. 3). Thus, the shoulder should be produced by the neutrons defocused by the SSM. The ratio of the focused to defocused neutrons by the SSM in case 2 is estimated to be 50 times larger than that in case 1, based on the polarization of 0.957 ± 0.035 of the incident beam. In case 2, therefore, such a shoulder should be unobservable, because the contribution of the defocused neutrons to the intensity distribution is buried under the background level. The differences of the peak values between cases 1 and 2 and the shoulder values between cases 1 and 3 are considered to result from the neutron transmission of the polarizer.

The ratio R of the peak value to the background level of the intensity distribution of a direct beam is one of measures which are often used to evaluate SANS instruments. In general, R is desired to be larger than $\sim 10^4$. Here, we define R_{mag} as the ratio of the peak value to the level of defocused neutrons for the SANS instrument with focusing geometry using the sextupole magnet. $R_{\mathrm{mag}} \sim 8000$ can be achieved even in the experimental condition of case 2 which is not optimized for a high R_{mag} value. Around the experimental condition of this study, R_{mag} is approximately proportional to $(\Delta\lambda/\lambda)^{-1}$. By optimizing the experimental condition, R_{mag} is expected to be increased by several times. The details will be discussed elsewhere. Therefore, the level of the defocused neutrons by the SSM can be sufficiently reduced by the same way as in this study, and $R_{\mathrm{mag}} > \sim 10^4$ can be achieved in the FSANS experiment with the sextupole magnet.

4. Conclusion

We have investigated the neutron focusing effect of the SSM using unpolarized and polarized cold neutrons to discuss the feasibility of the application of the sextupole magnet to FSANS experiments. The experimental setup, which consisted of the polarizer, the spin flipper, the SSM, etc., worked as expected. By utilization of the polarizer with efficiency of 0.957 ± 0.035, the level of the defocused neutrons could be reduced to be $\sim \frac{1}{8000}$ of the peak value of the direct beam. The level is expected to be further decreased by optimizing the experimental condition. Thus, we conclude that the sextupole magnet can be employed as a focusing device for FSANS experiments.

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