Development of a triplet magnetic lens system to focus a pulsed neutron beam

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Abstract. A triplet magnetic lens system composed of three sextupole-magnets and two spin flippers was constructed to focus pulsed neutrons in a wide wavelength range with same focal lengths. In this study, we performed a pulsed neutron beam focusing experiment with the system. The design of the system and the experimental results are shown and discussed.

1. Introduction

A magnetic neutron lens based on a sextupole magnet functions as a focusing and defocusing lens for neutrons with positive and negative spin polarity, respectively [1-4]. By combining the focusing and defocusing functions of the magnetic lenses, we can control neutron beam shape and divergence with high degree of freedom (Fig.1) [5,6]. Adiabatic field connection and spin flipping device make it possible to realize such a multiplet magnetic lens system (Fig.1) [5,6]. As the magnetic lens has neutron wavelength-dependent focusing property, namely chromatic aberration, it has been proposed that the chromatic aberration can be compensated in the pulsed neutron beam focusing by changing the focusing and defocusing functions of the magnetic lenses of the multiplet magnetic lens system synchronously with time-of-flight of neutrons [7]. This idea was verified based on a numerical simulation [8]. In this study, we designed and constructed a triplet magnetic lens system composed of three sextupole permanent magnets and two spin flippers, and performed a pulsed neutron beam focusing experiment with the system. The design of the system and the experimental results are shown and discussed.

2. Experimental setup

In this study, we constructed a triplet magnetic lens system composed of three sextupole permanent magnets and two spin flippers, and performed a pulsed neutron focusing experiment at the beamline C3-1-2-1 (NOP) of JRR-3 at Japan atomic energy agency (JAEA). The sextupole magnet functions as neutron focusing and defocusing lens for neutrons with positive and negative spin polarity, respectively [1-4]. The three sextupole permanent magnets (M1, M2, M3) and two spin flippers (SF1, SF2) were located in series as shown in Fig. 1. The spin flippers were utilized to control spin polarity of neutrons incident into the sextupole magnet. Based on the numerical simulation, the system was designed so as to satisfy a focal condition for neutrons in the wavelength range as wide as possible for the beamline. The experimental setup is shown in Fig. 1. The neutron beam was pulsed by using a

chopper, and then polarized by using a quadrupole magnet (Fig. 1). The neutrons which transmit through the quadrupole magnet is highly polarized with polarization degree P>0.99 [9, 10]. The pulsed polarized neutrons are delivered through the guide field and enter the triplet magnetic lens system. The spatial intensity distribution of the neutrons, which transmitted through the triplet magnetic lens system were measured by using a 2d-position sensitive detector [11].

The spin flippers are the Rf-gradient spin flippers which are designed to have flipping efficiency $f >$ 0.99 for neutrons with $\lambda > 4$ Å [12]. The spin flippers are turned on and off by turning on and off the Rf-current. The Rf coils are connected to a LC circuits with the resonant frequency of about 80 kHz. Fig. 2 shows how fast the Rf-current rises up and down when the spin flipper is turned on and off. The rising and falling times are about 200 μsec which is fast enough for this experiment.

The spin flippers are controlled to be on and off synchronously with time-of-flight of the neutrons. A start signal is sent out from the chopper and sent to delay modules which delay the signals for some times. The delayed signals as triggers are sent to function generators to turn on the spin flippers (Fig. 3).

3. Results and discussion

At first, we performed the pulsed neutron focusing experiments of the triplet magnetic lens system without changing the spin flipper state synchronously with the time-of-flight of the neutrons. The spin flipper states were fixed during the single measurement. The measuring conditions are shown in Table 1. The measured full widths at the half maximum (FWHMs) of the neutron beam focused onto the detector position are plotted as a function of the neutron wavelength λ in Fig. 4. It was found that neutron focal wavelength changes depending on the spin flipper states. The focal condition of the magnetic lens based on the sexupole magnet is determined by the magnet length and λ as follows:

$$ f = \frac{L_{mag}}{2} + \frac{h}{\sqrt{G\alpha}\, m_n \lambda} \cot\left(\frac{\sqrt{G\alpha}\, m_n \lambda}{h} \cdot \frac{L_{mag}}{2} \right) \tag{1} $$

Here, f is the focal length, L_{mag} the magnet length (Fig. 5), h Plank's constant, G the coefficient of the magnetic field gradient, $\alpha = |\mu_n/m_n| = 5.77\,\mathrm{m^2 s^{-2} T^{-1}}$, m_n the neutron mass and μ_n the neutron magnetic moment. By changing the states of the spin flippers at the wavelength λ_{CO} at which the FWHM curves of Fig. 4 cross over, we can satisfy the focal condition for the pulsed neutrons in a wide wavelength range. Then, we performed the pulsed neutron focusing experiment by turning on and off the spin flippers SF1 and SF2 synchronously with the time of flight of the neutrons at the cross over wavelengths λ_{CO1-3} (Fig. 4). The obtained results are shown in Fig. 4. As the result, the neutron beam size at the detector position were realized to be the narrowest among the cases 1 to 4, and the FWHMs were kept less than 4 mm between $\lambda = 7.4$ Å and 10.8 Å (Fig. 4).

The magnetic lens system is applicable to a focusing geometry small-angle neutron scattering (FSANS) instrument with pulsed neutrons. In the application, pulsed neutrons in a wide wavelength range should be focused with a fixed focal length for efficient utilization of the neutrons. Moreover, the neutrons should be focused on the detector so sharp that the peak tail intensity goes down to the background level rapidly. Fig. 6 shows the radial averaged intensities of the neutrons focused onto the detector. It was found that the neutron intensities in the wavelength range from $\lambda = 7.4$ Å to 10.8 Å decrease sharply down to the background level with increasing distance from the peak center (Fig. 6) Therefore, the magnetic lens system is considered to be applicable to the FSANS instrument with pulsed neutrons.

4. Conclusion

We have constructed a triplet magnetic lens system composed of three sextupole magnets and two spin flippers to focus a pulsed neutron beam in a wide wavelength range with same focal lengths. We performed the pulsed neutron beam focusing experiment with the system. By choosing the focusing or defocusing functions of each sextupole magnet adequately and synchronously with the time-of-flight of the neutrons, we could focus the neutrons in a wavelength range of between $\lambda = 7.4$ Å and 10.8 Å

with nearly same focal length. As the application of the magnetic lens system, it is considered to be applicable to a neutron focusing device for the FSANS instruments with pulsed neutrons, since we can focus the pulsed neutrons in a wide wavelength range so sharply onto the detector by using it.

References

[1]   P.S. Farago, NIM. 30 (1964) 271.
[2]   A. Steinhof. NIM-A 397 (1997) 371.
[3]   H.M. Shimizu, et al., Physica B, 241-243 (1998) 172.
[4]   H.M. Shimizu, et al., NIM-A 430 (1999) 423.
[5]   T. Oku, et al., Appl. Phys. A 74[Suppl.] (2002) S261.
[6]   T. Oku, et al., Proc. of SPIE 4509 (2001) 96.
[7]   J. Suzuki et al., the presentation at the International symposium on Pulsed Neutron and Muon Science, IPS08.
[8]   T. Oku, et al., NIM-A 600 (2009) 100.
[9]   T. Oku, et al., Physica B 397 (2007) 188.
[10] T. Oku, et al., Meas. Sci. Technol. 19 (2008) 034011.
[11] K. Hirota, et al., Phys. Chem. Chem. Phys. 7 (2005) 1836.
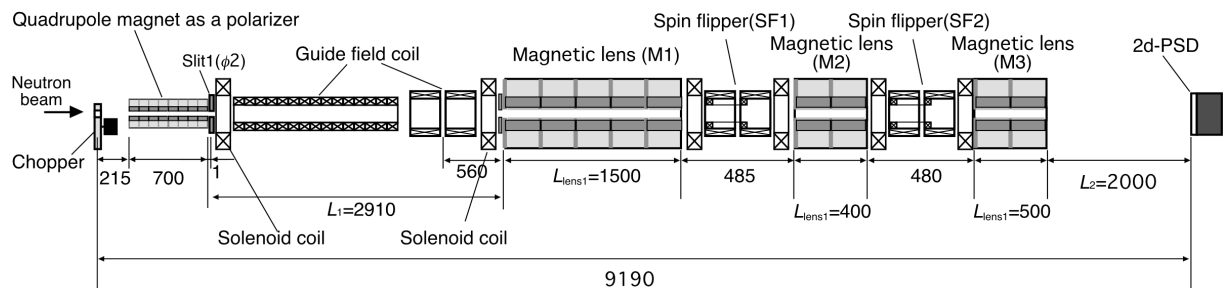[12] T. Oku, et al., Physica B 335 (2003) 226.
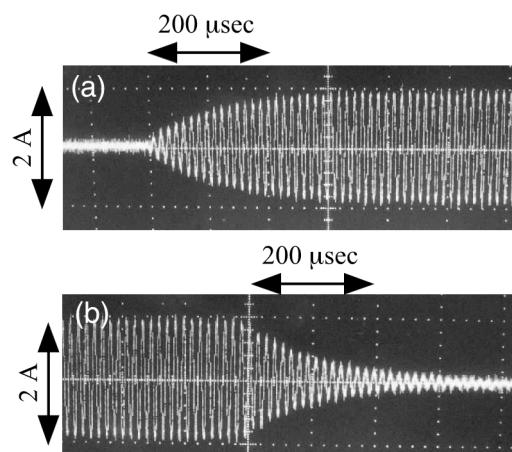
Fig. 1 Experimental setup.

Fig. 2 The Rf-current of the spin flipper when the spin flipper is (a) on and (b) off.
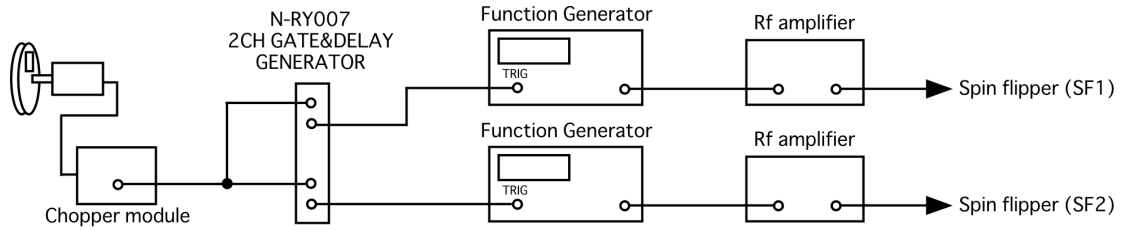
Fig. 3 A schematic signal processing circuit to control the spin flippers synchronously with the time-of-flight of neutrons.

Table 1 The states of the spin flippers and functions of the magnetic lenes

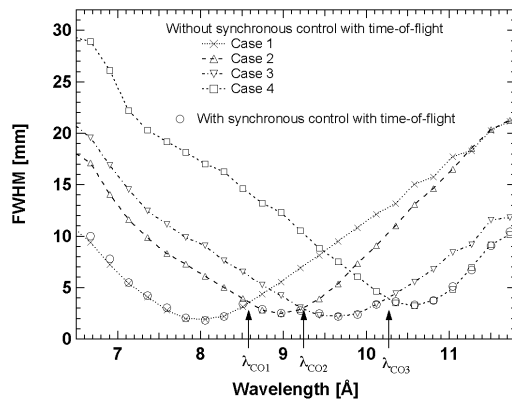| Case	States of the spin flippers		Functions of the magnetic lenses		
	SF1	SF2	M1	M2	M3
1	Off	Off	Focus	Focus	Focus
2	Off	On	Focus	Focus	Defocus
3	On	On	Focus	Defocus	Focus
4	On	Off	Focus	Defocus	Defocus

Fig. 4 The FWHM of neutron beam focused onto the detector position as a function of the time of flight of the neutrons.
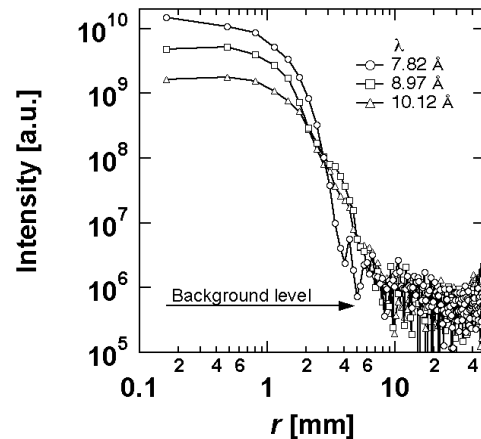

Fig. 6 Radial averaged intensities of the neutrons focused onto the detector.
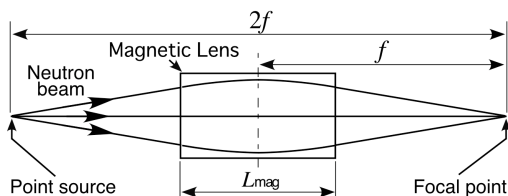

Fig. 5 A schematic layout of a magnetic lens which focuses the neutron beam with local length f.