Development of neutron beam control devices using magnetic field

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1. Introduction

To use the neutrons from a source as efficient as possible is very important for performing the beam experiments effectively. For the effective use of neutrons development of transport methods or devices are indispensable.There are several types of methods for neutron transportation. One is the neutron guide or the mirror using the reflection of neutrons on the surface. The second is material lens or magnetic lens using refraction of neutrons. In Japan we have Neutron Optics (NOP) Group to develop the neutron optical devices for the beam control. As a part of this activity we are developing the neutron magnetic lens. Neutrons have magnetic moment and interact with magnetic fields. So, we can control neutron beam by using the magnetic field. By using sextuple magnetic field we can make focusing lens [1-2]. The neutron focusing experiments using a permanent magnet lens system were performed at Hokkaido electron linac facility at Hokkaido University in Japan [3]. We used the linac as a fast neutron generator, and the neutrons were slowed down in a cold neutron moderator. We analyzed the neutron energy by using the time-of-flight method. Now, pulsed neutron sources of JSNS (Japan Spallation Neutron Source) and SNS in the USA are under construction. Therefore, focusing of pulsed neutron is required. Here, we present principle of the magnetic lens, and simulation results for a pulsed magnetic lens.

2. Principal

In the case of parallel and anti-parallel case of the neutron spin to the magnetic field B, following equation is obtained

$$\frac{d^2\mathbf{r}}{dt^2} = \mp\alpha\nabla|\mathbf{B}|$$

Here, $\alpha = |\mu/m_n| = 5.7688252\ \mathrm{m^2\,s^{-2}\,T^{-1}}$.

The solution is expressed by

$$\begin{pmatrix} x & y \\ \xi & \eta \end{pmatrix} = \boldsymbol{M}\begin{pmatrix} x_0 & y_0 \\ \xi_0 & \eta_0 \end{pmatrix}.$$

Here, $\xi = \dfrac{dx}{d\theta} = \dfrac{1}{\omega}\dfrac{dx}{dt}, \eta = \dfrac{dy}{d\theta} = \dfrac{1}{\omega}\dfrac{dy}{dt}$,

$\theta = \omega t$, ω is rotational frequency of magnetic field, and M is expressed by

$$\mathbf{M} = \begin{cases} \mathbf{M}_P = \begin{pmatrix} \cos\theta & \sin\theta \\ -\sin\theta & \cos\theta \end{pmatrix} & \text{Parallel case} \quad , \\ \mathbf{M}_A = \begin{pmatrix} \cosh\theta & \sinh\theta \\ \sinh\theta & \cosh\theta \end{pmatrix} & \text{Anti-parllel case} \end{cases}$$

For the neutrons with spin parallel to the local magnetic field, the magnetic lens works as convex lens and for the other neutrons as concave lens. So, the half number of neutrons is focused.

In the pulsed neutron source the neutrons arrive at a sample position at different time, which is proportional to inverse of their speed, and in the beam experiment a wide wavelength range of neutrons is usually used. Therefore, it is desired to focus the neutrons in a certain wavelength region at once. For such purpose a pulsed magnetic lens is required. Our JAERI and RIKEN groups made such a lens and installed at Hokkaido linac facility to test its performance. The magnetic field of the lens varies according to a function proportional to $1/t^2$, where t is flight time. Maximum gradient of the field is $8000\mathrm{T/m^2}$. The bore size is 22 mm and length is 200 cm.

As an attempt to look for a good experimental condition for checking the performance, we performed computer simulation to seek the best collimator arrangement.

3. Simulation for Collimator Arrangement.

Calculation setup is shown in Fig. 1. We put collimator in front of the lens and at 132 cm from the inlet of the lens. Flight path length is about 4.5 m.

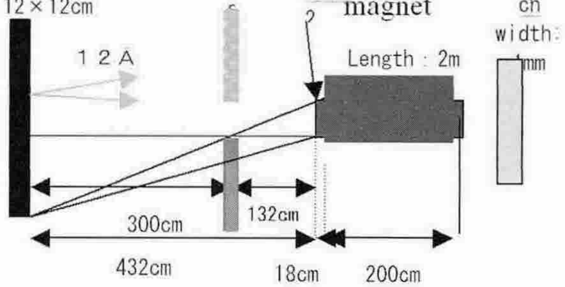

Fig. 1 Calculation model for magnetic lens

We chose 12A neutrons as a reference since in this lens 12-14A wavelength range is realistic to focus. Moderator size is $12x12cm^2$. Two sizes of slit 2 were studied, 22 and 26 mm, where 22 mm is the same size of the bore of the lens, and three sizes of slit 1 were studied, 2, 12 and 22 mm, in order to know the ratio between intensities with and without magnetic field, since higher intensity ratio makes it easier to see the effect of the magnetic lens. The pixel size of the position sensitive detector (PSD) is 1mm.
We simulate the time step of the time dependent magnetic field by dividing it into more than 10 steps.

3. Results and discussion

We first checked the focal position of the magnetic lens. Fig. 2 shows the intensity change as a function of the distance from the exit of the lens to the detector.

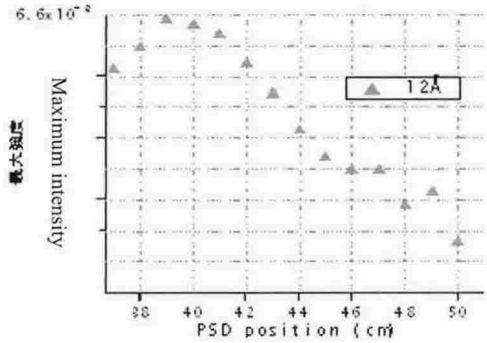

Fig. 2 Maximum intensity as a function of distance between lens exit and PSD.

The focal position is about 39 cm from the exit, and we put the PSD at this position. Concerning to the size of slit 2, 22mm in diameter was better than the 26 mm, so we chose 22 mm. After then we calculated the intensity ratios at different sizes of slit 1.The results are shown in Fig. 3.The x-axis of 'ch' means the number of the pixel, here, corresponding to the lateral position of the PSD. The intensity ratio using a 22 mm slit size gives highest intensity ratio among 1, 12 and 22 mm slit sizes, and the ratios of others are almost the same. By using the 22 mm slit we get about nine times higher intensity compared with the intensity without the magnetic fields. This indicates that the size same as the lens diameter is best from the intensity ratio point of view. However, focusing characteristics appears not so much, and the area of beam is almost the same among them due to the beam divergence of incident neutrons.

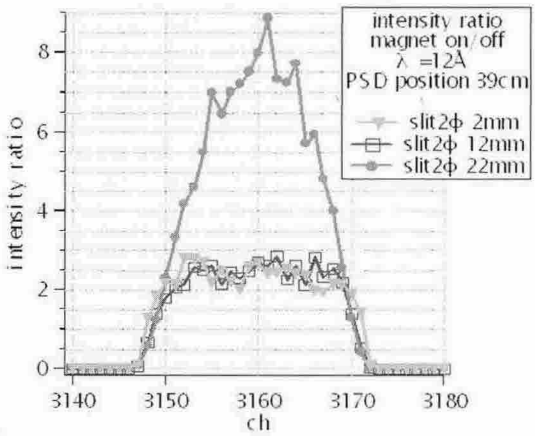

Fig. 3 Intensity ratio for various slit sizes.

4. Conclusion

A pulse magnet lens has been made for the use of beam control at a pulsed neutron source. To look for the good condition to check the performance of the lens we performed some simulation calculations. It was found that the highest intensity ratio was obtained under the condition of slits having the same diameter of the lens bore. However, the intensity distribution was not good indicator since there existed not so large difference in the spatial distributions.
We are still continuing the study to look for the best condition for the experiments performed near future.

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