ELSEVIER

Physica B 241–243 (1998) 172–174

PHYSICA B

Cold neutron beam control using magnetic field gradient

H.M. Shimizu[a,*], H. Kato[a], T. Oku[a], Y. Suda[b], Y. Ogawa[b], H. Iwasa[b], T. Kamiyama[b], Y. Kiyanagi[b], T. Wakabayashi[c]

[a] *The Institute of Physical and Chemical Research (RIKEN), 2-1 Hirosawa, Wako, Saitama 351-01, Japan*
[b] *Faculty of Engineering, Hokkaido University, Sapporo 060, Japan*
[c] *Power Reactor and Nuclear Fuel Development Corporation, Narita, O-Arai, Ibaraki 311-13, Japan*

Abstract

The focusing of a cold neutron beam in an inhomogeneous magnetic field was studied using a permanent sextupole magnet. Preliminary results show that neutron beam current density at a wavelength of 13 Å was enhanced by a factor of 30 after traveling through the sextupole magnet. © 1998 Elsevier Science B.V. All rights reserved.

Keywords: Instrumentation; Beam focus; Magnetic field gradient

A neutron trajectory can be bent in an inhomogeneous magnetic field according to the interaction between the neutron magnetic moment and magnetic field [1]. The neutron acceleration can be described by

$$\frac{\mathrm{d}^2\boldsymbol{r}}{\mathrm{d}t^2} = \mp\left|\frac{\mu}{m}\right|\nabla|\boldsymbol{B}|, \qquad (1)$$

as long as the neutron Larmor frequency is sufficiently large compared with the rotation frequency of the local field in the neutron rest frame. Here the $\mp$ signs correspond to the cases where the neutron spin is parallel and anti-parallel to the local field, and μ and m are the magnetic moment and mass of the neutron. The z axis is taken as parallel to the beam axis, and the x and y axes are perpendicular to the beam axis. In the case of sextupole field defined with a constant c as $|\boldsymbol{B}| = c(x^2 + y^2)/2$, the solution of Eq. (1) for the parallel case is given as

$$x,y = x,y|_{z=0}\cos\frac{zm\lambda\omega}{h} + v_{x,y}|_{z=0}\sin\frac{zm\lambda\omega}{h}, \qquad (2)$$

where $\omega^2 = |c\mu/m|$, λ is the neutron wavelength along z axis, and the distance z is measured from the entrance of the sextupole field. Half of the unpolarized neutrons entering the sextupole field are transported according to Eq. (2), while the other half are swept away from the beam axis. In the case where the incident neutron beam size is small and can be treated as a point source, the neutron beam is focused at a distance $z = \pi h/m\omega\lambda$.

*Corresponding author. Fax: + 81-48-462-4640; e-mail: shimizu@riken.go.jp.

0921-4526/98/$19.00 © 1998 Elsevier Science B.V. All rights reserved
PII S0921-4526(97)00542-5

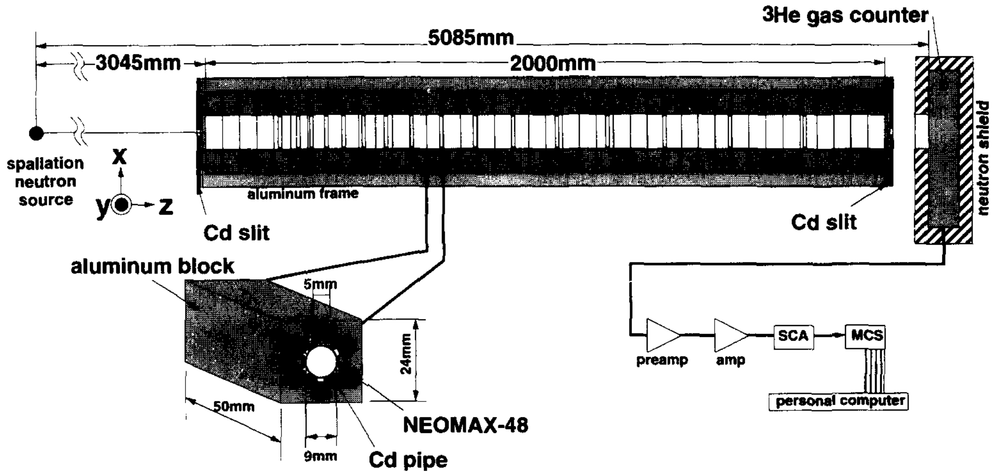

Fig. 1. A schematic view of the experimental arrangement.

The focusing effect of a sextupole field on a neutron beam has been studied by measuring the neutron transmittance through a permanent sextupole magnet using a pulsed cold neutron beam at the 45 MeV Electron Linear Accelerator Facility of Hokkaido University. The experimental arrangement is shown schematically in Fig. 1. A sextupole magnet was placed 3 m away from the surface of a liquid hydrogen moderator operated at 20 K. The effective area of the moderator was 10 cm (horizontal) × 3 cm (vertical). The sextupole magnet was 2 m long and consisted of 40 permanent sextupole units. Six permanent magnet pieces of 5 mm × 5 mm × 50 mm NEOMAX-48 [2] were inserted into holes of an aluminum block. The center hole of the aluminum block was 10 mm in diameter. Inner surface of the hole was partially covered by cadmium cylinders for the suppression of neutron reflection. The inner diameter of the cadmium cylinders was 9 mm. The strength of the sextupole magnet is estimated as $c = 4 \times 10^4\,\mathrm{T\,m^{-2}}$, which implies that a beam of 13 Å neutrons emitted from a point source at the entrance is focused after traveling 2 m in the sextupole field.

Cold neutrons transmitted through 2 mm diameter cadmium apertures placed at the entrance and the exit of the sextupole magnet were detected by a ^{3}He proportional gas chamber, and the signal was recorded by a multi-channel scaler. We denote the neutron count as a function of neutron wavelength as $N(\lambda)$.

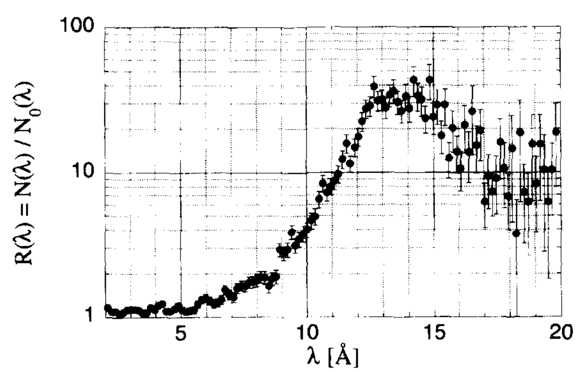

Fig. 2. The preliminary result of the measurement of $R(\lambda)$, the gain in neutron current density.

An identical configuration was prepared with non-magnetized NEOMAX-48 pieces. The neutron count obtained with the non-magnetized configuration is denoted as $N_0(\lambda)$. The effect of the magnetic field was measured as the deviation of the ratio $R(\lambda) = N(\lambda)/N_0(\lambda)$ from unity.

The preliminary result of the measurement of $R(\lambda)$ is shown in Fig. 2. Enhancement of the $R(\lambda)$ was observed at $\lambda \simeq 13$Å consistent with the point source focus condition, while $R(\lambda)$ was consistent with unity at shorter wavelengths where the focus effect is negligible. The maximum value of R reached more than 30, which is expected to be increased by covering the entire inner surface with neutron absorber because N_0 is still contaminated by neutron reflection.

The focused neutrons are spin polarized about the local magnetic field. Thus, a polarized beam can be obtained by transporting the neutron spin adiabatically into a flat field. The neutron beam divergence can be also controlled using the defocusing solution of Eq. (1) by transporting the neutron spin adiabatically into another sextupole magnetic field after flipping the neutron spin relative to the magnetic field. A more detailed discussion will be published elsewhere.

The authors are grateful to staffs of Development of Research Fundamentals Technology of RIKEN for the construction of the sextupole permanent magnets. This work was partially supported by the Grand-in-Aid Scientific Research under program number 09874086.

References

[1] P.S. Farago, Nucl. Instr. and Meth. 30 (1964) 271.
[2] Nd–Fe–B sintered magnet produced by Sumitomo Special Metals Co. Ltd.