Concepts of Neutron Polarisation Analysis Devices for a New Neutron Chopper Spectrometer, POLANO, in J-PARC

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Abstract. The basic concept of polarisation analysers with bender type supermirrors on the polarised neutron spectrometer, POLANO, which is now under construction in J-PARC/MLF, is described.

1. Introduction
The construction of a new polarisation analysis neutron chopper spectrometer, named POLANO [?] is now in progress in J-PARC/MLF, Tokai, Japan, as a collaboration project between High Energy Accelerator Research Organization (KEK) and Tohoku University. POLANO is a compact chopper spectrometer (L₁ = 17.5 m, L₂ = 2 m) with polarisation analysis ability, installed at BL23 (decoupled H₂ moderator) in the second experimental hall of MLF. The present status of this project is described by Yokoo et al. in this conference [?].

As already reported elsewhere [?, ?], a ³He spin filter with a continuous polarising spin exchange optical pumping (SEOP) system and a bender type supermirror device will be used as the polariser and analyser in the first stage of the project for investigations in the region of ε ≤30 meV. Discussions on the development and design of polarising devices are in progress under international collaboration.
In this short article, we estimate the parameters of the bender type supermirror analyser of POLANO based on Stewart’s calculations in Ref. 3. Figure 1 shows the definitions of the parameters of a bender type supermirror analyser in this text. For such analysers, the sample size is limited because of an acceptable angular divergency as shown in Fig. 2. The neutrons with an incident angle on the supermirror that is larger than the critical angle, $\theta_c$, cannot be reflected; that is, they cannot be detected at a detector. Thus, $L$ and $W$ must satisfy the following condition [1]:

$$\theta_c \geq \theta_{\text{max}} = \frac{W}{2L} \quad (1)$$

This directly means that samples with a large size within the scattering plane are not effective for instruments with supermirror-type analysers. Figure 2 shows the acceptable diameter of a sample for several $m$ values obtained from eq (1). Because of the structure of the sample vacuum chamber, the shortest $L$ for POLANO will be $\sim 55$ cm; this covers the solid angle of the scattered beams as much as possible. For $m=5$, which is almost the maximum value of commercial products at present, samples with a diameter of 20 mm can be used for $\sim 20$ meV, and 15 mm for 40 meV; these sample diameters are comparable to an incident beam size of $20 \times 20$ mm$^2$ at the sample position, which is given by the focusing guide tubes at POLANO [1, 2]. This means that $m=5$, (or 5.5 if possible) is the best choice for bender type supermirror analysers. Triple axis spectrometers with a polariser and analyser that show advantages in a few 10 meV region; thus, large $m$ supermirrors should be installed on POLANO to access a much wider energy region. We should point out that, for a cylindrical sample with a diameter of 10 mm, even scattered neutrons with $E_f \sim 60$ meV can be analysed with $m=5$ mirrors, in principle.
Next, we estimate the gap $d$ between adjacent mirrors and the minimum length of curved mirrors, $\ell$, the length of direct sight. To avoid a direct pass with no reflection on a mirror, $d$ and $\ell$ should satisfy,

$$\ell = (8Rd)^{1/2}$$

for $d \ll R$ [?]. On the other hand, for the reflection that does not touch the upper mirror, the garland reflection, $d$ and $R$ satisfy the following relation [?]:

$$\sin \theta_c = (2d/R)^{1/2}$$

Figure ?? shows $\ell$ for several $d$ for $m=5$ and 3.2 obtained from eq (2) and (3). Smaller $d$ values naturally give a shorter $\ell$; for instance, one can use a compact analyser system with $\ell \leq 100$ mm for $d=0.32$ mm for $m=5$ to analyser neutrons with energies up to 40 meV. However, because the substrate of borosilicate glass has a finite thickness (a typical value is $\sim 0.3$ mm), a smaller $d$ reduces the transmissions. For POLANO, we choose $d=0.7$ mm, for which the minimum mirror length $\ell$ can be approximately 230 mm for $m=5$ at $E=40$ meV; this length satisfies the space limitation. For a practical device, 1.3 times longer supermirrors ($\ell \sim 300$ mm) will be used to avoid the pass inside the substrate glass plates. Typical borosilicate glass includes approximately 10-13 wt% of boron; the transmitted neutrons through the substrate glass which degrade polarisation are negligible for $\ell \sim 300$ mm.

Typical expected values of the parameters of the supermirror analyser in the present design are summarised in Table 1. The vertical width is determined from the conditions of the magnetic fields which saturate the magnetisation of the supermirrors. One should be careful about the relation between $d$ and the total area of supermirrors; for a larger $d$, the number of supermirrors necessary to cover a particular scattering angle can be reduced, but the total area of the necessary supermirrors becomes larger; that is, the cost will increase.

The solid angles of the analyser are quite limited because of the size of the supermirror. Thus, we will use position sensitive detectors (PSDs) with a length of 600 mm centred at the equatorial plane, which is much shorter than the length of standard PSDs in J-PARC/MLF. Supermirrors with the parameters in Table 1 cover 76% of the length of a PSD. Because one PSD package of POLANO which consists of 32 PSDs covers the scattering angle $2\theta$ over a range of 18 °, the analyser device with $\sim 180$ mirrors in Table 1 corresponds well to one PSD package. The coverage of $2\theta$ is much smaller than the coverage of other polarisation analysis spectrometers in pulsed neutron sources, such as HYSPEC in SNS. Thus, the analyser device will be installed on a rotating table take measurements at different scattering angle positions up to $2\theta=120$ °. The number of supermirrors will be increased in stages in the future so as to cover larger solid angles.
Table 1. Summary of expected parameters of the supermirrors of the present design

| Parameter                  | Value                          |
|----------------------------|-------------------------------|
| \( m \) value             | 5.0 or 5.5 (concave surface)   |
|                            | 1.5 (convex surface)           |
| Optimised Energy           | 41 meV                        |
| Length, \( \ell \)        | 300 mm                        |
| Vertical width (sample side) | ~140 mm                     |
| Vertical width (PSD side)  | ~180 mm                       |
| Radius of curvature, \( R \) | 10.1 m                       |
| Gap (sample side)          | 0.7 mm                        |
| Gap (PSD side)             | 1.0 mm                        |
| Thickness of substrate     | 0.3 mm                        |
| Distance from the sample, \( L \) | 550 mm                    |
| No. of mirrors             | ~180                          |
| Covered 2\( \theta \) range | ~16°                         |

Though the supermirror analyser must be the best for the \( \epsilon \leq 30 \text{ meV} \) region, POLANO should be available in higher energy regions too. SEOP \(^3\text{He}\) spin filter analysers are now under development for the \( E_f \sim 100 \text{ meV} \) region in collaboration with KEK, JAEA, and Tohoku University. In particular, GE180 glass cells with a diameter of 10 cm have already been prepared in Tohoku University \([?]\). We will develop banana-shaped analyser cells for POLANO in this project as well. We are also developing the dynamic nuclear polarisation (DNP) technique in KEK with international collaboration, which is important for a higher energy polariser as well as for sample environment equipment for investigations of hydrides. For the further development of the DNP technique, as well as supermirror benders, discussions with PSI are in progress.

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