Design of multi-pinhole collimator system for SANS based on CPHS neutron source

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Abstract. A new design for Small Angle Neutron Scattering instrument based on utilization of multi-pinhole collimator is presented. The 7-pinhole structure has been proposed for 30 years by Glinka[1]. But due to the crosstalk issue, the SNR is not as high as traditional single-pinhole system. Luckily, software nowadays helps us to analyze the system and optimize the parameters of the collimator. With the help of 7-pinhole collimator instead of single-pinhole, we can approach almost one magnitude higher flux than before, which is valuable especially in compact pulsed neutron source, whose flux is a big issue.

1. Introduction

Small angle neutron scattering technique has been widely used since 1970s in many fields of research including physics, biology, material science, chemistry and so on. It is used to investigate material structures in the size range of 0.5 to 500 nm. In a standard SANS instrument, collimators of two or more apertures called single-pinhole system is used to get collimated neutron beam. However, in compact neutron source like CPHS (Compact Pulsed Hadron Source in Tsinghua University) whose neutron source flux is relative low compared with large facilities, as the neutron flux at sample determines whether or not the experiment’s statistics are good, single-pinhole collimator is not a very good choice. To overcome the low neutron intensity from source, we are now designing a new type of collimation system called multi-pinhole collimator system, which contains several single-pinhole collimators focusing on the same position at detector. This multi-pinhole collimator idea was proposed by Glinka originally in 1986[1], and it has been used in many VSANS instruments which achieves a lower Q than traditional SANS while keeps the neutron flux not decreasing too much.[2,3,4] Besides multi-pinhole collimator structure, other types of collimator can be used to increase neutron flux at sample. For example, soller collimator, which was invented at IPNS.[5] This type of collimator uses blades of neutron absorption material to absorb high divergence neutron. However, as the surface of blades is quite long, the reflection noise is a big issue need to be overcome. Multi-channel collimator is similar with soller collimator, while it’s collimated on radial direction, other than x/y direction separately.[6] In fact, soller collimator and multi-channel collimator can be regarded as a continuous multi-pinhole collimator. So it’s valuable to analyze multi-pinhole collimator as a general case, while continuous one is the specific case.

There are many inherent problems that limit the multi-pinhole collimator system to replace...
the usage of single-pinhole collimator system in traditional SANS instrument. The largest problem is cross-talk between each independent single-pinhole optic, and cross-talk can be produced by the placement of each collimator or parasitic scattering (including scattering from the thin layer, diffuse reflection, specular reflection and diffraction from the pinhole edge surface).[5] The cross-talk will lead to the uncollimated beam focus on the sample and thus reduce the SNR of the system. To make multi-pinhole system work, Glinka and Barker proposed to use beveled edge to prevent specular reflection and surface diffraction by low incident angle neutron, which can be called “open-angle” structure.[7] High neutron absorption material was used to reduce the thickness of the layer and thus the cross-talk problem can be diminished.[1]

2. Methods and Analysis

There are two main problems in multi-pinhole collimator system: crosstalk optics and specular reflection. For the crosstalk issue, the way to prevent is that either we can use smaller pinhole size to pinhole distance ratio, or we can use more collimator masks in the total beamline. Fig.2 shows the relationship of number of masks and pinhole size that won’t have crosstalk. The tradeoff between number of masks and size of pinhole is in fact that the problem of the flux at sample and aligning work hardness.

Second problem is the specular reflection issue. The way to eliminate such noise is to add an open-angle structure to reduce reflectivity of neutron on the surface. The reflectivity expression
is below:

\[ k = \sin^2 \theta \frac{2\pi}{\rho_{SLD} \lambda^2} \]  

\[ r(\theta) = \frac{1}{(\sqrt{k} + \sqrt{k-1})^2} \]  

(1)  

(2)

Here \( \theta \) is the incident angle, \( \rho_{SLD} \) is the scattering length density, \( \lambda \) is the neutron wavelength, and \( r(\theta) \) is the reflectivity.

By using the reflectivity expression, we can try to analyze the SNR of the system by adding different conditions, including absorbing material, neutron spectrum, neutron incident angle. Theoretically Signal to Noise result can be calculated by modeling. Figure 4 shows when considering specific neutron spectrum and neutron incident angle distribution, the SNR changes with the open-angle and thickness of collimator. By modeling, highest SNR can be found and thus can tell us what parameter can be used for the collimator.

![Figure 4. SNR of different open-angle and thickness for B4C material.](image)

Mcstas simulation was also carried on to see the neutron optics for the system. Figure 5 shows when virtual source input was used, while 10 collimator masks were put in the beamline, we can see the focused neutron on the detector. By calculating the SNR from mcstas output, the correctness of modeling can also be tested.

![Figure 5. Mcstas simulation result.](image)

3. Discussion

The choice of neutron absorption material is quite important. For solid material, Li-6, B-10, Cadmium and Gadolinium are most widely used. Table 1 shows the absorption cross section and gamma production of each material. It’s obviously seen that gadolinium has highest absorption
cross section, while it will produce high energy gamma. Oppositely, Li-6 has lowest absorption cross section, but it won’t produce any gamma. As gamma can be part of noise in the beamline, it’s worthy cutting down.

Table 1. The performance of different neutron absorption material.

| Element     | Absorption cross section for thermal neutron(barn) | Highest gamma energy(MeV) |
|-------------|---------------------------------------------------|---------------------------|
| Li-6        | 940                                               | 0                         |
| B-10        | 3836                                              | 0.478                     |
| Natural Cd  | 2520                                              | 9.05                      |
| Natural Gd  | 49700                                             | 8.89                      |

To overcome this problem, John Barker in NCNR proposed to use “sandwich” structure to eliminate the gamma effect.[8] While using Li-6 as the first layer can reduce the effect of gamma production, gadolinium can be added as last layer to assure the neutron be absorbed, and borated aluminum alloy can be used to maintain the strength of the collimator.

4. Conclusion
Multi-pinhole collimator was used to increase neutron flux at sample while maintain the Q resolution of system, but compared with single pinhole collimator, it still has many problems need to be overcome. Luckily, Modeling and Monte Carlo simulation can be used to analyze the performance and optimize the parameters of the system. In the near future, the setup of multi-pinhole collimator for VSANS instrument will give us information to see the real performance of such system.

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