Neutron Beam Conditioning for Focusing SANS Spectrometers

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Abstract. Multibeam focusing offers an appealing compromise between high resolution and high incident flux configurations for SANS spectrometers. In fact so many “spectrometers” operate in parallel as the number of channels in the collimator. Each channel provides high resolution by small spot size on the detector and long sample-to-detector distance, involving significant limitation of the transmitted beam phase space volume, thus reducing the flux. The flux on the sample is increased by the large number of channels. In view of the multibeam collimation it is beneficial to increase the beam cross section and decrease the divergence at the same time. Two aspects related to the use of rotational velocity selectors are investigated. First the transmitted phase space is determined from the selector parameters. It is found that the beam azimuthal divergence with respect to the rotor axis has a significant effect on the selectivity. Neutrons flying along different paths are treated differently, leading eventually to energetic non-uniformity of the illumination of various collimator channels. Then the effect of the gap in the neutron guide at the selector location on the phase space uniformity at the collimator entrance is investigated and optimal selector location along the beam is proposed together with optimal neutron guide shape in the vicinity of the gap, which accommodates the selector.

1. Introduction

The angular resolution of a small angle scattering instrument with geometry defined in Figure 1 is given by [1, 2]:

\[
(\sigma_\theta)^2 = \frac{1}{4} \left( \frac{r_f}{ld} \right)^2 + \frac{1}{4} \left( \frac{r_l(l+f)}{ld} \right)^2 + \frac{1}{12} \left( \frac{\Delta r}{d} \right)^2,
\]

where $\Delta r$ is the detector resolution. The smallest detectable scattering angle (Figure 2) is $\Delta \theta = r/d$. Small collimator aperture diameters and large collimation and focal distances ensure high angular resolution, but lead to significant limitation of the accepted phase space of the incoming beam.

The scattering vector resolution includes the selectivity of the velocity selector $\Delta k \lambda$:

\[
(\sigma_q)^2 = k^2(\sigma_\theta)^2 + \frac{k^2}{12} \left( \frac{a}{d} \right)^2 \left( \frac{\Delta \lambda}{\lambda} \right)^2,
\]

where $k = 2\pi/\lambda$. 

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The use of multibeam collimation ensures the increase of the flux illuminating the sample by the number of channels $n$. The collimator transmission parameter becomes:

$$A\Omega = \frac{\pi^2 l_1^2 r_2^2}{l^2}$$  \hspace{1cm} (3)

2. Neutron beam phase space adjustment
In order to accommodate a larger number of channels, the beam cross section has to be increased at the entrance of the collimator, especially when a relatively small cross-section beam feeds the instrument. This can be done by means of a beam expander (Figure 3), on the expense of divergence decrease (Figure 4), to the extent of fully illuminating all channels. The condition is that the reflection angles seen from the sample upstream through the collimator do not exceed the critical angle of the incoming guide supermirror. The expander shown in Figure 3 is 5.6 m long and transforms the beam cross section from a 25 mm square to a 56 mm high octagon. The collimator is 4 m long and one channel diagonal is 2.8 mm at the inlet and 1.4 mm at the exit. The direct beam spot diagonal on the detector is 5.6 mm.

![Figure 3. Beam expander](image)

![Figure 4. Middle and highest divergence paths in the collimator, beam expander and guide. The grey stripe is the optimal location of the velocity selector. Vertical : Horizontal scale: 100 : 1.](image)

The highest reflection angle in the beam expander: 0.4°, corresponding to $m = 1.33$ at 4 Å; inside the incoming guide: 0.69°, corresponding to $m = 2.29$ at 4 Å.

3. Velocity selector location
Gaps in a neutron guide imply dark stripes in the beam image when viewed through a pinhole. The stripes become wider with increasing number of reflections (Figure 5). The gap accommodating the selector would cause partially or totally “blind” channels.

![Figure 5. Dark stripes implied by a gap in a neutron guide](image)
As shown on Figure 4, close to the exit end of the neutron guide there is a region with low reflection angles, below 0.06°. Thus here is the optimal location of the velocity selector. Increasing the guide cross section by 0.6 mm all around, there will be no line of sight of the guide end upstream of the gap (Figure 6).

4. Velocity selector characteristics
The characteristics of a multiblade velocity selector of constant 48000 rpm Å have been determined by means of time-of-flight pinhole imaging (Figure 7). The beam image taken at 9600 rpm in the wavelength range 4 – 6 Å can be seen on Figure 8, together with selected summation areas corresponding to +/- 1° (a), +/- 0.05° (b), - 0.64° … - 0.54° (c) and 0.54° … 0.64° (d) azimuthal (horizontal) respectively +/- 0.25° radial (vertical) divergence.

The transmitted intensity distribution with respect to wavelength and azimuthal divergence at 1200 rpm (leftmost stripe), 9600 rpm and 8000 rpm respectively, at zero rotor tilt angle is mapped on Figures 9 and 10. The results show, in accordance with theory [3], that azimuthal divergence has a significant effect on the selectivity (Figure 11). This means that different channels of the collimator will be illuminated by slightly different wavelength neutrons depending on the divergence angle it imposes with respect to the beam axis, in azimuthal direction to the selector rotor axis. Better and more uniform selectivity could be obtained placing the selector between the expander and the collimator (the divergence accepted by the collimator is 0.21°). This would require
larger selector window – rotor diameter, and more space for radiation shielding. The selectivity curves as a function of rotor tilt angle and symmetrical azimuthal divergence range are plotted on Figure 12.

**Figure 10.** Transmitted intensity distributions at several tilt angles, with respect to wavelength and azimuthal divergence. Rotation speed: 12000 rpm

**Figure 11.** Transfer functions at 8000 rpm - the effect of azimuthal divergence

**Figure 12.** Selectivity as a function of rotor tilt angle

5. **Conclusions**

Aspects of neutron beam conditioning in view of the multibeam collimation for focusing SANS instruments have been investigated. Solutions for beam phase space adjustment are proposed together with optimal selector location and neutron guide shape in the vicinity of the gap, which accommodates the selector. Thorough experimental verification of the selector transfer functions is presented.

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