Transactions of the Korean Nuclear Society Spring Meeting
Jeju, Korea, May 18-19, 2017

A Neutron Ray Tracing Simulation of Tapering Optics on the Cold Neutron Guide 5 of the HANARO Cold Neutron Research Facility

J. M. Sungil Park [a*], Baek-Seok Seong [a]
[a]*Neutron Instrumentation Division, Korea Atomic Energy Research Institute, 111 Daedeok-daero 989beon-gil,*
Yuseong, Daejeon 34057, Korea
[*]*Corresponding author: jmsaprk@kaeri.re.kr*

1. Introduction

The Cold Neutron Research Facility at HANARO houses a few cold neutron guides with a provision for thermal neutron guides. The successful deployment of cold neutron beam instruments in the guide hall of CNRF is partially thanks to extensive simulation efforts on guide performances. In modern neutron optics, it is becoming increasingly important to conduct computer simulation before the construction commences to optimize the optics and save costs.

The cold neutron guide 5 (CG5) hosts the cold neutron triple-axis spectrometer (Cold-TAS) at the end of it. The guide is made of m=2 supermirror and is 15 cm tall and 5 cm wide from start to finish. There is a curved section in the middle that filters high energy neutrons and gamma radiation from the reactor so that only cold neutrons enter the instrument. While providing ample amount of cold neutrons, 5 cm wide beam is often considered “very wide” – it is the widest beam available at CNRF and is difficult to shield. Unless the beam path is very well shielded and optics optimized, neutron flux that misses the sample often is the cause of an elevated noise level. It might be, therefore, beneficial to limit the beam width to a smaller one. Often beam slits are employed for such tasks, but gain in neutron flux cannot be expected by using them while gamma radiation is bound to increase depending on the neutron absorbing material used.

One way of resolving this issue is to introduce a tapering neutron guides in the middle of the guide system. In theory, highly reflective neutron guides used as a tapering guide would maintain the total number of neutrons, thus boosting the resultant neutron flux higher than when only the straight guides are used. We conducted a series of simulations on a few different geometries on the CG5 to see whether real benefits could be found by changing the optics to limit the beam size at the sample position.

Table I. The geometry of CG5

Distance from the source	1.917 m
Declination Angle	2.5°
Supermirror Quality	m = 2
Guide Width × Height	5 cm × 15 cm
Length, In-pile Guide	4.684 m
Curvature, Curved Guide	1,500 m
Length, Curved Guide before SS	24 m
Secondary Shutter (SS)	20 mm
Length, Curved Guide after SS	2 m
Straight Guide before NVS	11.944 m
Neutron Velocity Selector (NVS)	0.571 m
Straight Guide after NVS	3.936 m
Guide-Monochromator Distance	0.300 m
Monochromator-Sample Distance	2.000 m

2. Methods and Results

2.1 Neutron ray tracing package

For simulations, McStas, the well-known neutron ray tracing package was used [1]. Compared to the other widely used neutron ray tracing package, Vitess, it has more flexibility at the cost of ease of use. The simulation results from these two packages are considered identical [2].

2.2 Guide geometry and initial simulations

The guide geometry for the Cold-TAS has widely changed from the previous study [3]. The instrument was put on CG5 instead of CG4. The detailed geometrical parameters of CG5 are listed in Table 1.

We conducted two simulations based on this geometry, which we believe reflects the current instrument setup. The first simulation does not use a beam slit and the reflected beam from the monochromator approaches the sample position without hindrance. The second simulation places a couple of slits between the monochromator and the sample, both of them set at a 5 cm width. The slits are located 30 cm after the monochromator and 30 cm before the sample respectively.

The maximum flux at the sample is essentially identical for the two cases, while the total flux is only

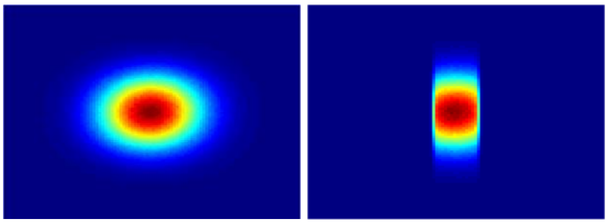

Fig. 1. Simulated result showing neutron flux at the sample position with the current CG5 geometry. (Left) Open beam path between the monochromator and the sample. (Right) Two 5 cm wide slits are located between the monochromator and the sample.

about half for the latter case because the slits limit horizontally diverging neutrons from arriving at the sample position as shown in Figure 1.

2.3 Narrowing the beam width to 3 cm

The flexibility of computer simulation allows widely imaginative guide geometries. One such geometry is to use a 3 cm wide guide from the start. Compared to the 5 cm wide guide, the loss of flux is evident as shown in Table II. Close to half of all neutrons are lost when identical supermirrors are used between the two cases. Note that even when m=8 guides are used when the width of the guide system is 3 cm, the maximum flux and the total flux is significantly smaller than when the width is 5 cm.

Instead of changing the guide widths to 3 cm from the start, a tapering guide can be placed in the middle of the guide system to induce a gradual change in the width and preserve as many neutrons as possible. For this study, we began by adjusting the slit width close to the sample. The “tapering” was gradually pushed upstream, and the result is tabulated in Table III.

One can easily observe that placing the 3 cm wide slit close to the sample maintains the maximum flux while reducing the total flux. We can expect an enhanced signal to noise ratio with this setup as long as the sample size remains small.

By limiting the beam width to 3 cm further upstream, we inevitably start to see the reduction of the maximum flux at the sample. Interestingly the ratio between the maximum and total flux peaks when all the guides are kept at a 5 cm width and the two slits between the monochromator and the sample are open at 3 cm. Although this ratio does not directly translate into a higher signal to noise level, it is worth noting that limiting the beam width indeed might have a positive effect.

Table II: Neutron flux at the sample position simulated with constant-width guide systems

Width & m values	Max Flux ($\times 10^7$ n/cm^2/s)	Total Flux ($\times 10^7$ n/cm^2/s)
5 cm, m=2	1.91	47.8
5 cm, m=8	2.08	59.7
3 cm, m=2	1.03	15.8
3 cm, m=8	1.10	19.3

Table III: Neutron flux at the sample position simulated with tapering guide systems. The 4 width values correspond to the width of the upstream and downstream guides and the two slits between the monochromator and sample. Supermirror m is fixed at 2.

Width (cm)	Max Flux ($\times 10^7$ n/cm^2/s)	Total Flux ($\times 10^7$ n/cm^2/s)
5-5-5-5	1.91	47.8
5-5-5-3	1.92	30.0
5-5-3-3	1.59	23.3
5-3-3-3	1.24	18.9
3-3-3-3	1.03	15.8

2.4 Use of the higher m supermirror guides

The logical next step to recover some of the lost neutron flux at the sample position is to replace the m=2 supermirror guides to higher m-value supermirror guides. Currently the best supermirror guide commercially available boasts m=8 [4]. More neutrons reflect by higher m-value supermirrors. Note, however, the added neutrons mostly have higher divergence. Therefore, the benefit of exchanging the guides with higher m-value supermirrors cannot be great if the downstream optics do not accommodate a highly divergent beam.

Indeed, that is what is observed with the tapering guide system with the 3 cm wide slits placed between the monochromator and the sample. Simulations were carried out for different m-values for the upstream, tapering and downstream guides. We used either m=2 that reflects the current geometry or the best available m=8 for the replacing guides. The results are compared in Table IV along with the previous result that used only m=2 supermirrors.

More neutron flux is present when m=8 is used from upstream to downstream as expected. However, the gain is mere 12% even when m=8 supermirror guides are used far-upstream close to the cold neutron source. More “realistic” realization of having m=8 guides for the tapering and downstream guides only produces 7% boost. Considering the cost, it is difficult to justify the use of expensive supermirrors on CG5.

Table IV: Neutron flux at the sample position simulated with tapering guide system. The three m values represent the supermirror m values for the upstream, tapering, and downstream guides.

m values	Max Flux ($\times 10^7$ n/cm^2/s)	Total Flux ($\times 10^7$ n/cm^2/s)
8, 8, 8	1.39	24.2
2, 8, 8	1.33	20.5
2, 2, 8	1.27	19.4
2, 8, 2	1.25	19.2
2, 2, 2	1.24	18.9

3. Conclusions

Neutron ray tracing simulation has been carried out on tapering optics of CG5. Whatever geometry was used, the loss of neutron flux at the sample position was persistent. The use of higher m-value supermirrors did improve the flux, but not quite recover the original flux even when m=8 supermirrors are used, contrary to the simple argument used in the introduction.

While the loss of neutron flux due to the tapering geometries is clear, gain in the overall signal to noise might be possible by limiting the beam to a 3 cm width after the monochromator. However, because there is no known tool available to assess the signal to noise ratio of a neutron scattering instrument, any modification to the optics must be approached with extreme care.

REFERENCES

[1] K. Lefmann and K. Nielsen, McStas, a General Software Package for Neutron Ray-tracing Simulations, Neutron News, Vol.10, p. 20, 1999.
[2] P. A. Seeger, L. L. Daemen, E. Farhi, W.-T. Lee, X.-L. Wang, L. Passell, J. Saroun & G. Zsigmond, Monte carlo code comparisons for a model instrument, Neutron News, Vol.13, p. 24, 2006
[3] Sungil Park, Monte Carlo Simulation of the Cold Neutron Guide for the HANARO Cold Neutron Triple-Axis Spectrometer, Korean Nuclear Society Autumn Meeting, Nov. 2-3, 2006, Gyeongju, Korea.
[4] http://www.swissneutronics.ch/