Upgrade of the neutron guide system at the OPAL Neutron Source

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Abstract. The new research reactor at ANSTO (OPAL) is operating with seven neutron beam instruments in the user programme and three more under construction. The reactor design provides for expansion of the facility to eighteen instruments, and much of the basic infrastructure is already in place. However, an expansion of the neutron guide system is needed for further beam instruments. For this purpose, several possibilities are under consideration, such as insertion of multi-channel neutron benders in the existing cold guides or the construction of a new elliptic cold guide. In this work Monte Carlo (MC) simulations have been used to evaluate performance of these guide configurations. Results show that these configurations can be competitive with the best instruments in the world.

1. Introduction
The new research reactor at ANSTO (OPAL) is operating and seven of the first-wave neutron beam instruments are complete [1]. Three instruments, currently in design phase, are also expected to begin operation in the next three to four years. These instruments are powerful resources for condensed matter and materials physics research, and will provide high quality research outputs for Australia over the next decade. As the requirements of neutron beam science grows and diversifies there will be a demand for expansion of the research capabilities at OPAL. This will require new instruments as well as periodic improvements to existing instruments. Further expansion of the instrument suite beyond those under construction will require upgrade of the neutron guide system to provide additional neutron beams matched to the performance requirements of new instruments.

The design process for the original neutron guide system began in 1998, relying mainly on Monte-Carlo (MC) simulation methods [2]. The system was finally built and commissioned by 2007; a period of around nine years. In recognition of the long lead time for upgrade of the guide system, we are now evaluating a range of designs for splitting of neutron beams and for creating more end-guide positions.

One possibility is insertion of multi-channel benders to fully exploit the potential of the existing cold neutron guides [3]. Different neutron bender designs have been evaluated in the present cold guides and their performance assessed for some potential new instruments.

Another possibility is insertion of new guides. The simplest approach would be insertion of large curved parallel sided supermirror guides between the existing guides (and similar in design to the existing guides). However, in recent years non-linear tapered guides have been built in some neutron laboratories with impressive performance [4]. In particular elliptical guides have been shown to deliver outstanding performance in transporting and focusing neutrons. For this reason, the design of elliptical guides is being considered as well.
2. Description of the simulated systems

MC simulations of possible modifications to the OPAL cold beam transport system were performed using VITESS program [5]. The source term is based on measurements of the characteristics of the OPAL cold neutron source (a 20 litre re-entrant liquid Deuterium moderator) [6]. The source is modeled as a flat rectangle (at the beam tube entrance), which has a cold spectrum in the central part (of the same area as the beam tube) and a thermal spectrum on either side. The sides account for neutrons that are either underthermalized in the cold source, or that travel from the cold source through the D₂O reflector and are partially re-thermalized on the way to the guide entrance. Therefore, the neutron spectrum is a sum of two Maxwellian distributions at 45K and 300K.

In the existing cold neutron guides, the beam tube is ~1.35 metre long and is followed by a 3 metre long supermirror guide up to the reactor face, and then by a 20.5 m. long curved guide section until the secondary shutter.

![Fig. 1 schematics of a) a multichannel bender on CG3 and b) an elliptical cold guide between CG1 and CG3.](image)

2.1. Creation of more guide end positions in existing guides with benders

The most obvious choice for insertion of a multichannel bender is CG3 (a cold guide), upstream of the PLATYPUS (the neutron reflectometer at OPAL). The cross-section of CG3 from source to secondary shutter is 20 x 5 cm, but PLATYPUS only uses the top 2 x 5 cm, leaving most of the beam free. The supermirror coating of the guides in the straight sections has m=3 for top and bottom parts and m=2 on the sides, while in the curved guide section m=2.5 in the outer side of the guide and in the rest is the same as the straight sections [2]. To minimize disturbance the bender must bypass the Platypus crane. This can be achieved by a combination of bender and straight guide (see Fig. 1 a). The bender must have short radius of curvature (ρ), and a large number of channels. Here we consider 16 or 32 channel benders and substrate thickness of 0.25 or 0.50 mm. (typical thickness of Si or glass substrate respectively). Several combinations with differing relative lengths of bender (L) and straight guide (Lst) sections have been simulated (see table 1 for details).

| L (m) | ρ (m) | Lst (m) |
|-------|-------|---------|
| 1.0   | 4.1   | 13.16   |
| 2.0   | 8.0   | 12.33   |
| 3.0   | 11.5  | 11.29   |
| 4.0   | 14.7  | 10.27   |
| 5.0   | 17.7  | 9.32    |
| 6.0   | 20.3  | 8.31    |

Table 1: Parameters of the simulated multichannel benders where L is the bender length, ρ is the radius of curvature and Lst is the length of the straight guide placed after the bender and up to a position adjacent to PLATYPUS crane.
2.2. Insertion of an elliptic cold guide

There is space for insertion of another guide between the two existing cold guides. Here we consider elliptical guide geometry. Fig. 1 b) shows the sketch of the simulated elliptical guide. The entrance of the guide is at the end of the cold neutron beam tube and is elliptic in two dimensions. The minimum guide length required to access free floor space beyond PLATYPUS is 41.5 m. Various lengths have been simulated between 41.5 m and 1000 m. Although this range greatly exceeds the length of the OPAL neutron guide hall, analysis of longer lengths will show the limits of performance. In order to filter fast neutrons and gamma radiation from the reactor core two beam stops (ideal absorbers) with the same area as the guide entrance and exit are placed half way along the guide, separated by 50 cm. We have evaluated guide performance at the sample position (of area 3x3 cm) for two possible future instruments; a Small Angle Neutron Scattering (SANS) instrument and a Neutron Spin Echo (NSE) spectrometer. In these simulations the distance from guide end to sample are 3 m and 6 m, for NSE and SANS respectively.

| Guide length (m) | Focus at 3 m. (NSE) | Focus at 6 m. (SANS) |
|------------------|---------------------|---------------------|
|                  | Height (cm) | Width (cm) | Height (cm) | Width (cm) |
| 41.5             | 41.09     | 10.28     | 31.69     | 7.92     |
| 61.5             | 48.50     | 12.13     | 36.52     | 9.13     |
| 81.5             | 54.93     | 13.74     | 40.80     | 10.20    |
| 101.5            | 60.68     | 15.18     | 44.68     | 11.17    |
| 251.5            | 93.14     | 23.30     | 67.03     | 16.76    |
| 501.5            | 130.38    | 32.61     | 93.04     | 23.26    |
| 751.5            | 159.13    | 39.80     | 113.24    | 28.31    |
| 1001.5           | 183.75    | 45.88     | 130.34    | 32.59    |

Table 2: Height and width at the guide centre of the simulated elliptical guides

3. Results of simulations of multi-channel benders

The dependence of total flux on bender length is plotted in Fig. 2a. We see that flux peaks at bender length of 5-6 m. or 3 m. for 16 channel or 32 channel benders respectively. We also see the strong dependence of flux on substrate thickness. Wavelength dependence of bender transmission (Fig. 2b) shows that long benders (and 32 channels) favour short wavelengths over longer wavelengths, but a short 16 channel bender is far superior for very cold neutrons. We can qualitatively explain these trends by recognising the shift from garland to zig-zag reflections with increasing wavelength.

Fig. 2: a) Flux at the end of the straight guide for selected simulated benders. b) Wavelength dependence of transmission for selected benders (d=0.25 mm).

In order to benchmark potential instrument performance after the bender arrangement (Fig. 1a), we calculated flux at the sample position in either a medium resolution SANS instrument or a NSE spectrometer. Results indicate that a 32 channel bender in the length range 4 - 6 m., delivers highest
usable flux at $\lambda \sim 6$ Å. Maximum calculated fluxes for a SANS instrument are $4.2 \times 10^7$ or $1.5 \times 10^7$ n/cm$^2$/s for 2.5 m. or 5 m. collimation length, respectively. By comparison, calculated sample flux, at $\lambda = 6$ Å, on QUOKKA (the SANS at OPAL) with 1 m. or 8m. collimation length is $1.8 \times 10^8$ or $2.6 \times 10^7$ n/cm$^2$/s, respectively[7]. For a NSE spectrometer, our calculated flux is $1.7 \times 10^7$ n/cm$^2$/s at $\lambda = 6$ Å, around half that of the IN11 spectrometer at ILL ($\sim 3.2 \times 10^7$ n/cm$^2$/s [8]). These comparisons indicate that bender options really are competitive for such neutron beam instruments.

4. Results of simulations of a cold elliptic guide

Comparison of the dependence of total flux on elliptic guide length with that of OPAL’s existing cold guides (Fig. 3 a & b) shows radically different trends. Whereas flux delivered to sample decreases with increasing length in the existing guides, the elliptic geometry shows the opposite trend, with increasing flux up to guide lengths of order ~ 800 m. This surprising trend illustrates the main advantage of elliptic geometry; that the number of reflections of transmitted neutrons decreases markedly with increasing guide dimensions.

![Graph comparing flux and guide length for elliptic and existing guides](image)

Fig. 3 a) Comparison of total flux at sample position for elliptic (elipt.) and existing (ref.) guides, and b) gain in flux of an elliptic guide over OPAL existing guides.

5. Conclusions

The neutron optical concepts considered here show promise for construction of additional competitive cold neutron instruments in the OPAL neutron guide hall. It is possible with multi-channel benders to provide high flux cold beams to instruments placed at large angles to the existing beam trajectories. Preliminary simulations of elliptical guides indicate the possibility of outstanding performance in the transport of neutrons over very long distances. A more thorough study is being made about the reliability of this kind of guides to the OPAL Neutron Guide Hall.

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