Neutron Spectral Brightness of Cold Guide 4 at the High Flux Isotope Reactor

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Abstract. The High Flux Isotope Reactor resumed operation in June of 2007 with a super-critical hydrogen cold source in horizontal beam tube 4. Cold guide 4 is a guide system designed to deliver neutrons from this source with a reasonable flux at wavelengths greater than 4 Å to several instruments, and includes a 15-m, 96-section, 4-channel bender. A time-of-flight spectrum with calibrated detector was recorded at port C of cold guide 4, and compared to McStas simulations, to generate a brightness spectrum.

1. Introduction

The High Flux Isotope Reactor (HFIR) at Oak Ridge National Laboratory resumed operation in June of 2007 with a super-critical hydrogen cold source in horizontal beam tube 4. Neutron scattering instruments that view the cold source receive an enhanced neutron spectrum for wavelengths greater than 4 Å. A time-of-flight measurement that viewed the moderator directly, when nearest guide sections were removed,\textsuperscript{1} compares fairly well with previous MCNP model results, as shown in Figure 1. They disagreed above 3 Å, where brightness was fortunately better than expected, with a 60% increase at 5 Å before the guide.

Cold Guide 4 is a guide system designed to deliver neutrons with wavelengths between 2 Å and 6.4 Å from this source at reasonable flux to several instruments, and includes a 15-m, 96-section, 4-channel bender with total deflection of \(8^\circ\), with a vertical trumpet, as shown in Figure 2a. A typical neutron will bounce about 12 times in getting through the \(8^\circ\) bend, so the transmission through the bender depends strongly on the quality of the mirror coatings.

In this paper we report the results of a new time of flight measurement after the guide system, at a position where a cold neutron triple axis spectrometer will be installed.
Table 1. Fit parameters for a 3 Maxwellian function manual fit to measured spectral brightness as shown in figure 3A.

| Maxwellian | $I_0$   | $T$  |
|------------|---------|------|
|            | (n/s/cm$^2$/ster/Å) | (K)  |
| 1          | 7.5E12  | 300  |
| 2          | 3.3E13  | 64   |
| 3          | 7.0E12  | 22   |

Figure 1. The spectral brightness of the HB-4 cold source at reactor power level of 85 MW and moderator temperature of 22.5 K as measured, modeled and fit using parameters in Table 1. The arrows indicate aluminum Bragg edges.

2. Experiment and Simulation

A time of flight spectrum with a calibrated detector was recorded at port C of cold guide 4, using an apparatus described elsewhere\(^1\). It consisted of three components: a disk chopper, a neutron detector, and a data acquisition system for processing the detector signals. The guide, chopper and detector are shown in Figure 2. The disk chopper is a rotating disk with the rotation axis parallel to the neutron beam and is used to cut the continuous neutron beam into short pulses. To produce the pulses, the disk has a slot through which the neutrons can pass as the slot rotates through the beam and the neutron ‘window’ opens. The disk is 1 cm of boron nitride backed by 0.7 mm of cadmium, which together block the neutron beam while the neutron window is closed. The chopper disk is preceded by an entrance aperture consisting of a 2.54 cm thick plate of boron nitride with an opening sized, shaped and aligned to match the slot in the chopper disk. The angular width of the neutron window was set at 1.8°, with a radial extent between 11.0 and 12.7 cm. The detector is a Reuter Stokes parallel plate fission counter with the anode located 2.451 m from the center of the chopper disk. The detector was shielded on all sides by 1 cm of boron nitride and 0.7 mm of cadmium. A circular entrance aperture with a diameter of 9.5 mm was machined into the detector shield. The data acquisition system is a Peripheral Component Interconnect (PCI)-based multichannel scaler triggered by an optical pickup on the chopper disk, with 10 μs bins, corresponding to 0.016 Å, and controlled by in-house LabView software. The DAQ system integrated the spectrum for 18,000 pulses then saved the data, cleared, and began a new histogram. In this way we could monitor any changes in the spectral brightness over time with an approximately fifteen-minute granularity.

Differences between the current and previous setup are the use of a 20 Hz chopper frequency instead of 60 Hz, a distance between the middle of the chopper to the detector of 2.451 m, instead of 2.473 m, and a detector aperture of diameter 9.5 mm instead of 10 mm.

In our McStas\(^2\) simulation, we employed a source term that was a sum of three Maxwellians, fit to the measured brightness determined previously\(^1\), as shown in Figure 1 with manually determined fit parameters listed in Table 1. In this way we can evaluate the performance of the guide system alone.
3. Results

Figure 3 shows measured neutrons per second at the detector, compared to the McStas simulation. This plot accounts for detector efficiency in the measured data. For the modelled data it accounts for (incoherent) attenuation in aluminium windows and in air, and beam reactor power. No attempt was made to account for the effects of Bragg scattering or multiple scattering by the air or aluminium. The wavelength offset of the measured data was roughly set using the dip in intensity at the (2 0 0) and (1 1 1) aluminium Bragg peaks, but with such a broad convolution in wavelength, the offset could easily be off by ~0.1 Å.

We measured an unexpected background signal at ~8% of the measured peak flux, roughly independent of time. This background was not observed in the previous study at the HB4 beam tube. For the plot, it was subtracted from the data prior to scaling by detector efficiency for comparison, but it will be further analyzed. The measurements will not be repeated however, because a monochromator shield has been installed at the port C for the cold neutron triple axis spectrometer.

To obtain brightness at the end of the guide from measured neutrons per second at detector as shown in Figure 3b, we first account, on both model and measurement, for the wavelength-dependent chopper transmission $f$, due to finite disk thickness (0.01 m). Here $f = 1 - \lambda / \lambda_{\text{m}}$, where for 20 Hz $\lambda_{\text{m}} = 92.5$ Å. An analytical form of the acceptance in the detector is difficult due to the presence of both rectangular and circular apertures, but an approximation leads to an acceptance of $6.8 \times 10^{-6}$ cm$^2$ str, the same acceptance used in the previous study$^1$. We assume 100% power instead of 10% power, and correct for transmission through air and aluminium after exiting the guide. We account for the chopper duty factor of 0.005. For the measured data we again account for detector efficiency. Finally, no attempt was made to deconvolve either the measured data or the McStas results with respect to the chopper slot time window, which corresponds to a width of 0.404 Å.

4. Discussion and Summary

In Figure 3, we note that the measured and modelled transmission of the guide match very well for wavelengths above 3.5 Å, and the measured transmission is slightly better than that modelled between 2 Å and 3.5 Å. Below 1.5 Å, the measured count rate is slightly less than that modelled, but this is in part due to a slight overestimate of the source term as shown in Figure 1. Comparing Figures 1 and 3b, the aluminium Bragg edges are broader post-guide due to the use of a 20 Hz chopper frequency instead of 60 Hz for the disk chopper frequency. It is unclear how much of the flux loss near these edges is due to the aluminium scattering. The spectra at short wavelengths is more difficult to compare due to the uncertainty in the wavelength offset of the measured data, the steeper slope below 2.5 Å, and aluminium Bragg edges between 2 Å and 3 Å.
We were pleasantly surprised that a known septa misalignment problem did not significantly impact the guide system transmission. We knew that the bender septa were misaligned, due to theseptas of varying thickness lying in oversized slots. On one assembly of 6 sections, we measured at each end a typical gap of ~40 μm or 8% of the width of the Si plates, and found the plates lying loosely in the slots. We therefore performed McStas studies to estimate flux loss from misaligned septa occlusion, and found that for this typical gap attenuation may be up to 50%, independent of wavelength. The model results shown assume no misalignment.

Based on these results, we can proceed with installation of several new instruments, including a new cold neutron triple axis spectrometer, and a quasi-Laue diffractometer, confident that we can predict the performance of these instruments.

We wish to acknowledge the efforts of Ralph Moon, who developed the design concept of, and developed an earlier model for, all four guide systems for horizontal beam tube 4 at HFIR. This experiment was supported by the Department of Energy’s Office of Science.

References
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Figure 3. (a) Neutrons per second at the detector as measured and modeled, for a reactor power level of 8.5 MW. The arrows indicate aluminum Bragg edges and the ‘No Al Powder’ line is a guide to the eye for locating these edges in the measured data. (b) The spectral brightness at port C of cold guide 4, at reactor power level of 85 MW, as measured and modeled.