Operational performance characteristics of the WISH detector array on the ISIS spallation neutron source

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ABSTRACT: The performance of the position sensitive neutron detector array of the WISH diffractometer is discussed. WISH (Wide angle In a Single Histogram) is one of the seven instruments currently available for users on the second target station (TS2) of the ISIS spallation neutron source, and is used mainly for magnetic studies of materials. WISH is instrumented with an array of 10 detector panels, covering an angular range of 320°, orientated in two semi-cylindrical annuli around a central sample position at a radius of 2.2m. In total the 10 detector panels are composed of 1520 3He based position sensitive detector tubes. Each tube has an active length of one metre, a diameter of 8mm and is filled with 3He at 15 bar. The specification for the WISH detectors included a neutron detection efficiency of 50% at a neutron wavelength of 1Å with good gamma rejection. A position resolution better than 8 mm FWHM along the length of the tubes was also required which has been met experimentally. Results obtained from the detector arrays showing pulse height and positional information both prior to and post installation are shown. The first 5 of the 10 detector panels have been operational since 2009, and comparable diffraction data from powder and single crystal samples taken from the remaining 5 panels (installation completed in 2013) shows that we have a detector array with a highly stable performance which is easily assembled and maintained. Finally some real user data is shown, highlighting the excellent quality of data attainable with this instrument.

KEYWORDS: Neutron detectors (cold, thermal, fast neutrons); Neutron diffraction detectors; Gaseous detectors

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1 Introduction

The ISIS spallation neutron source [1], located at the Rutherford Appleton Laboratory, produces neutrons and muons for fundamental research in the physical and life sciences using the techniques of diffraction, reflection and spectroscopy. Neutrons are produced when a high intensity beam of 800MeV protons is fired at a tungsten target. The neutrons are then moderated and transported down beamlines to sample positions enabling the various science techniques to be applied. Two target stations exist on ISIS, TS1 and TS2, at which 18 instruments view one target and another seven view the second target with the capacity to increase this by another 11. The second target station became operational in 2009 and WISH was one of the seven phase 1 instruments built. The WISH instrument [2] is a long-wavelength diffractometer primarily designed for Time Of Flight (TOF) powder diffraction from magnetic and large unit cell systems, which will provide high resolution data over a d-spacing range of 0.7–17Å with a single frame bandwidth of 8Å. The neutron beam is transported from the target by a ballistic supermirror guide, which is elliptical in the horizontal and vertical planes. The guide starts at 1.7m from the source and ends 0.5m from the sample point: the primary flight-path of the moderator face to the sample position being 40.0m. Position sensitive detectors, located at a constant distance of 2.2m from the sample position, on both sides of the sample tank cover neutron scattering angles between 10° and 170°, ± 15° out of the plane, which can be seen in the photograph in figure 1.

2 The WISH detectors

The position sensitive detectors used on WISH are single wire proportional tubes, which have been supplied by GE Reuter-Stokes [3]. The tubes are formed from 0.4mm thick stainless steel, are 8mm in diameter and have an active length of 1m. A thin resistive wire runs along the length of each tube which serves as the detector anode with the stainless steel tube acting as the cathode. The tubes are made neutron sensitive by using $^3$He as the detector gas through the nuclear reaction:

$$^{3}\text{He} + \_0\text{n} \rightarrow ^1\text{H} + ^1\text{H} + 764\text{keV}$$
Figure 1. Photograph of detector array and sample tank inside the WISH blockhouse.

The tubes are filled with 15 bar of $^3$He which corresponds to a theoretical detection efficiency of 50% for 1Å neutrons. Argon is used as a stopping gas in order to reduce the range of the proton and triton and to minimise the wall effect, typical of this type of detector [4]. The tubes are precision mounted onto a support panel which in turn is mounted to an assembly jig. Each panel carries 152 of these tubes and also houses the preamplifiers and high voltage connections necessary for the operation of the tubes. Each tube is supported at four points, aligned within 300µm, to guarantee that the wire sits in the centre of the tube to avoid damage under high tension. Two of these points are at the tube ends through a right angle connection into the preamp housing, the other two support points being along the length of the tube where the tube is pulled down to a support by a thin stainless steel strap attached to a non-magnetic spring. The WISH instrument comprises 10 such panels, 5 on either side of the sample tank in a semi-circular formation. Boron carbide shielding is mounted onto the panels behind the tubes in order to reduce neutron backscatter. The total weight of each panel is approximately 100kg. Once assembled the panels were then rigorously tested before transfer and installation into the WISH blockhouse. The five panels on each side of the sample tank cover a detection area of $1 \times 6m^2$ giving a total active detection area of $1 \times 12m^2$. Signals from the panels are sent via 40m cables to a remote counting house where custom made readout electronics boards process the data, ready for analysis. The resistive anode wire ($\sim 8k\Omega$) is readout at both ends by means of a bipolar amplifier with 200ns integration time. The differential output signals are then digitised with custom built ADCs with 33 MHz sample rate and 14 bit resolution.

2.1 Preliminary detector testing

The initial testing of the WISH prototype detectors was performed on the ROTAX beam line [5] in order to evaluate the position resolution of the detectors and to develop the signal processing and the gamma/neutron discrimination algorithms. Five detector tubes were exposed to a collimated neutron beam, formed from a 2 mm wide cadmium (which is neutron absorbing) slit at several positions along the length of the tubes. The digitised signals, from both ends of the tubes, were filtered with an integrating and differentiating recursive formula [6]. The filter that optimises the position resolution is a gaussian filter made of four integration stages, each with an integration time of 125ns, and a differentiation stage with a differentiating time of 1µs. The filter minimises noise components, approximates the signal to a gaussian shape and cancels any offset introduced
by the preamplifiers. The position of the neutron interaction is determined by the charge centre of gravity method. Figure 2 shows the response of one of the tubes under test with the collimated beam illuminating the centre of the tube. A position resolution of 7mm FWHM is obtained at the nominal operating voltage of 1450V, which increases to 8mm towards the ends of the tube. The digital signal processing needs to preserve the position resolution of the detectors up to the maximum count rate of the tube, which has been shown experimentally to be 150kHz [7]. This necessitated the use of a base line restorer which is implemented in FPGAs on the ADC boards in conjunction with the signal processing algorithms.

The FPGAs also permit the pulse height distribution of the tube to be measured by simply summing the signal from both ends of the tube, which is an important diagnostic tool in determining the tube’s working condition. Figure 3 shows the pulse height distribution obtained from one of the tubes, illuminated by an $^{241}$Am:Be source. The response from a $^{60}$Co gamma source has been superimposed on the same plot. Discrimination of the two types of event is important due to (n,γ) reactions arising from neutron absorption in the sample, sample environment or the local instrument environment. A simple pulse height discrimination is not sufficient to distinguish between the two types of event, particularly at high rate. An algorithm based on the analysis of the pulse shape was developed which is a cut in the 2D space obtained from the time derivative of the signal at the low level discriminator threshold (LLD = 5mV) and the pulse amplitude, see figure 4. In this space the broad separation between gammas and neutrons guarantees a good discrimination (1 in $10^6$), up to a rate of 150kHz. This discrimination algorithm is also implemented in the FPGAs on the ADC boards.

### 2.2 Panel assembly and testing

The 10 WISH panels were assembled on a rotisserie with 360 degree rotation allowing ease of assembly and subsequent source testing. Each panel consists of 152 tubes and is instrumented with ten 24 channel preamplifiers and two 32 channel preamplifiers. The panels were designed
Figure 3. Pulse height spectra of a WISH tube at 1450 V illuminated by an $^{241}$Am:Be source and a $^{60}$Co gamma source.

Figure 4. 2D space used for neutron gamma discrimination: time derivative at the low level discrimination threshold (5 mV) versus pulse height.

to fit together inside the block house to enable seamless coverage in angle between panels, thus removing any dead area, which is especially important for single crystal diffraction data. This is accomplished by means of triple axis adjustment on the frame that the panel is mounted to inside the WISH blockhouse. Once assembled each panel was illuminated with a $^{241}$Am:Be source and both pulse height and positional data were obtained. Typical pulse height and positional data from
a whole panel are shown in figures 5 and 6. Figure 5 shows pulse height data for a complete panel under neutron irradiation at the required operating point. As can be seen, tube 130 has the highest gain on the panel, but the deviation from ‘normal’ across the whole panel is minimal at <5%. Tubes that substantially deviated from planar, exhibited a much larger gain than normal and were subsequently removed.

Figure 6 shows position data from the same panel. Only two, 24 channel ADCs were used to test the whole panel, and the source was moved between acquisitions. The eight channels at the top of the plot had a separate acquisition. The large systematic shift in the positioning, particularly at channel 17 (repeated at channel 65 and 113) are due to tolerances in the ADCs which were calibrated out once installed in the WISH blockhouse. There is also a small stagger (of the order of 3mm) from tube to tube, due to the positioning of the tubes in the support plates. Any tubes which exhibited any sparking were easily highlighted in these plots and the tubes removed for further investigation.

The panel has been designed such that a faulty tube can be removed and replaced once installed in the blockhouse. This requires minimal disassembly (only one preamplifier needs to be removed) and takes about 1 hour to perform. Since installation, of the order of three tubes per panel have had to be replaced, which have generally been caused by the move into the blockhouse.

3 Operational performance

Once assembled and tested, the detector panels were installed into the WISH blockhouse and aligned ready for commissioning with a neutron beam. The first five panels were fully operational and available to the ISIS user community in 2009. The second five were commissioned for use in 2013 giving the full 320° angular coverage. Once installed, the position resolution of each tube was measured at nine equidistant positions along its length by using a curved aluminium sheet coated with a gadolinium painted mask. The mask was composed of nine slits, each 3 mm wide and
was individually mounted on each panel to collimate the neutron beam. A typical position spectrum is shown in figure 7(a) and a composite image from the first 5 panels (760 tubes) is shown in figure 7(b). An excellent uniformity was achieved over the whole array of 7±1 mm FWHM, within the WISH specification of 8 mm FWHM.

Preliminary testing with standard powder and single crystal diffractometer samples, as both types of sample are studied on WISH, gave excellent results even for short collection periods. For example, figure 8(a) shows a data set obtained from the single crystal BaMnF$_4$. The crystal is $10 \times 8 \times 2$ mm$^3$ and the data set had an acquisition time of 12 minutes. Figure 8(b) shows a data set obtained from a silicon powder sample, in a similar acquisition time. The Debye-Scherrer cones are easily identified. Both data sets were obtained when only 5 panels of detectors were available.

Once the second batch of detector panels was installed and aligned it was important to check that the data quality from both sides of the sample tank was equivalent. Figure 9 shows a diffraction data set obtained from a powder sample of Na$_2$Ca$_3$Al$_2$F$_{14}$, which is another commonly used calibration sample. Again the Debye-Scherrer rings are easily identifiable. At first glance the images
from both sides appear to be identical, but we can take a closer look by using the neutron time of
flight (TOF) data obtained from the sample under study.

This can then be analysed in order to determine the sample’s crystal and/or magnetic structure,
and figure 10 shows the reconstructed data for the two panels that measure the largest back scat-
tering angles, panels 5 and 6. An excellent agreement between the two panels is obtained, with a
slight increase in the measured intensity of the Bragg reflections observed from panel 5 compared
to panel 6. Figure 11 shows a comparison of all other corresponding panels, through the 90 degree
scattering (figure 11(b)) to the most forward scattering (figure 11(d)). Again an excellent agreement
between the detector panels is shown, with the same slight increase in measured intensity from the
first 5 panels that were installed (panels 1–5). The cause of this discrepancy is as yet unknown, and
it can be easily normalised out with a standard sample. In this way the quality of the refined data
remains unaffected.
Figure 10. Bragg reflections from a sample of $\text{Na}_2\text{Ca}_3\text{Al}_2\text{F}_{14}$ in the most back scattering panels.

Figure 11. Comparative plots from four other panels of the Bragg reflections from a sample of $\text{Na}_2\text{Ca}_3\text{Al}_2\text{F}_{14}$.

4 Discussion and future work

The complete detector array for the WISH diffractometer has now been successfully installed and commissioned. The position resolution of the whole array is as expected and specified leading to excellent data quality. To date, WISH is now producing the largest volume of data from any of the ISIS TS2 instruments. In the very near future two large tanks filled with argon will fill the void between the sample vacuum vessel and the detectors in order to reduce neutron scattering from the 1.5m air path that currently exists. This should improve the data quality even further, especially in the forward scattering region.

Acknowledgments

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