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Performance studies on high pressure 1-D position sensitive neutron detectors

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Abstract. The powder diffractometer and Hi-Q diffractometer at Dhruva reactor make use of five identical 1-D position sensitive detectors (PSDs) to scan scattering angles in the range 3° to 140°. In order to improve the overall throughput of these spectrometers, it is planned to install a bank of 15 high-efficiency and high-resolution PSDs arranged in three layers with five PSDs in each layer. With each high pressure PSD (^{3}He 10 bar + Kr 2 bar) showing the efficiency gain of 1.8 at 1.2 Å, detector bank is expected to show overall gain of 5.5 times the present detection efficiency and reduction in data collection time by equivalent factor. The 1-D PSDs are developed in batches of five, and are characterized so that all PSDs operate at uniform parameters such as position resolution, uniformity of efficiency and linearity of response. Position spectrum indicates the differential position resolution to be ∼1 mm and integral position resolution to be 3–4 mm. Broadening of position spectrum at the extreme end of sensitive length of PSD is analysed using fine shift of the beam. Dependence of position resolution and dynamic range of output pulse on the input impedance of pre-amplifier is also presented.

Keywords. Gas-filled proportional counters; position sensitive detectors; neutron scattering and diffraction.

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1. Introduction

Position sensitive detectors (PSDs) play an important role in neutron scattering studies. Demand on PSDs with higher scanning angles and better position resolution leaves one with the choice to optimize these two properties. The desirable properties are good efficiency, uniformity of response, and linearity over the sensitive length, position resolution and operational stability [1,2]. A number of indigenously developed PSDs are mounted at various neutron spectrometers at Dhruva reactor and are operated with an excellent stability over a long period. High Q and powder diffractometers are presently equipped with a multi-PSD system with five cylindrical PSDs covering angular range of 140°. Each PSD with a sensitive length of ∼88 cm covers an angular range of 26° with an absorbing gas thickness of 35 mm in radial direction showing efficiency of 58% at 1 Å, position resolution of ∼6–7 mm, and stable operation. Other instruments at Dhruva reactor such as

Table 1. Details of 1D PSD installed and proposed for various neutron spectrometers.

Instrument	Detector	Number of 1-D PSDs Present	Number of 1-D PSDs Proposed	Fill pressure	Efficiency at 1 Å (%)
Hi-Q diffraction	36D PSD	5		4 bar + 2 bar	58
spectrometer			15	10 bar + 2 bar	85
Powder	36D PSD	5		4 bar + 2 bar	58
diffractometer			15	10 bar + 2 bar	85
Quasi-elastic	24D PSD	1		3 bar + 1.5 bar	52
spectrometer			1	4 bar + 2 bar	58
SANS	36D PSD	1		3 bar + 1.5 bar	52
spectrometer					
Polarized neutron	8E PSD	1		3 bar + 1.5 bar	63
reflectometer					

SANS spectrometers, spin echo spectrometer, polarized neutron reflectometer and quasi-elastic spectrometer are also equipped with similar type of gas-filled PSDs, designed specifically for the application and instrument shielding constraints. Table 1 gives the details of PSDs used on all the instruments.

Rise in ^{3}He pressure improves the efficiency, but it puts some constraint by causing tolerance and increase in rise time of the pulse. Thus after optimizing the maximum pressure to 10 bar of ^{3}He, further attempt to increase the counting efficiency is made by intercepting the higher scattered beam height. This can be achieved by stacking more PSDs over the angular range and intercept the higher beam height. Detailed study on the effect of anode material, fill gas pressure of ^{3}He and various stopping gases on the properties such as detection efficiency and position resolution is explained in detail elsewhere [3,4].

Powder diffractometer and high Q diffractometer are in the process of installing 15 PSDs in stacking geometry with the 5 PSDs in one layer and stack of three such layers. All these PSDs need to show identical performance and operating parameters. The fabrication of PSDs is therefore, undertaken with great care to hold high fill pressure and maintain the admixture concentration accurately. The results of one stack of 5 PSDs developed and tested for the performance at Apsara beam no. 9 are given in this paper.

2. Experiment and results

The detector made of brass and fill tube made of copper with higher wall thickness are used for high pressure tolerance of the detector. Detectors are filled with ^{3}He (10 bar) + Kr (2 bar). Performance of these detectors is studied using Apsara reactor neutron beam for pulse height and position spectra. Open beam of 5 mm wide and 50 mm height is incident on a PSD to record the pulse height spectra. The beam consists of neutron flux of 10^6 n/cm^2/s and gamma flux of 2 R/h. Figures 1a and b show the pulse height spectra of a PSD recorded with single end and

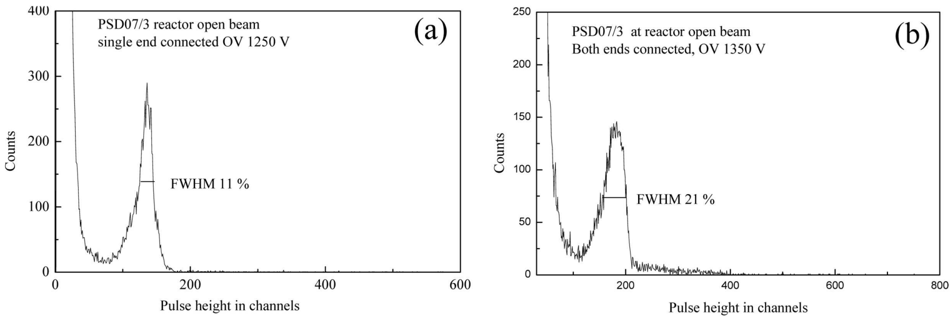

Figure 1. Pulse height spectra of a PSD with (**a**) single and (**b**) both ends connected.

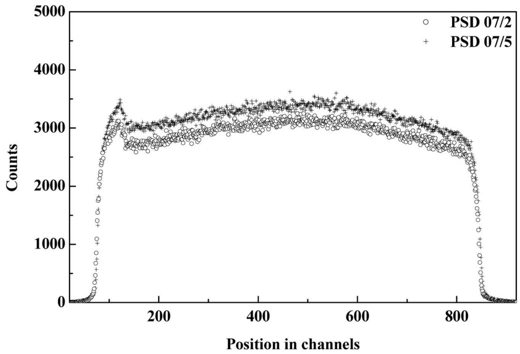

Figure 2. Flood pattern showing the uniformity of efficiency for PSDs with Pu–Be source exposed parallel to the detector length. Data for only 2 of the 5 PSDs are shown for the sake of clarity.

both the ends respectively connected to pre-amplifiers. It shows the reduction in pulse height as charge is recorded from both the ends and gets divided, though the internal amplification remains same. Broadening of pulse is due to the rise in input impedance due to the other pre-amplifier.

The charge division read-out method is used for obtaining position information. Same electronics set-up is used for all PSDs to rule out any systematic errors. Initially PSD is exposed to uniform flux of neutrons from a Pu–Be source kept parallel to the detector at a distance of 1.5 m $\pm$ 5 cm. Figure 2 shows the uniformity of response of the PSDs recorded for 2000 s. Data for only PSDs are shown for the sake of clarity. Hump on the left side arises due to discrimination level, which was eliminated in a later stage. No deformity or kink in the anode wire is observed. Rise in efficiency at the central part of the detector is due to the source detector geometry. The difference in efficiencies of the detectors is perhaps due to variation in the source–detector distance because of shifting of source inside the moderator box. The efficiencies are observed to be uniform ($\pm$3%) in the plateau characteristics, recorded without changing the position of source.

Position spectra for the PSDs are recorded using 1.5 mm collimated beam and placing the detector in the deal wood shielding. Figure 3 shows the position spectra

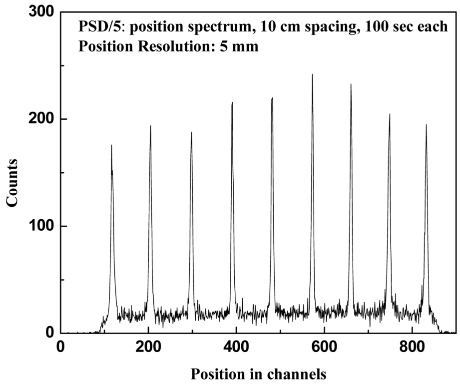

Figure 3. Position spectrum with 1.5 mm collimated beam with a shift of 10 cm.

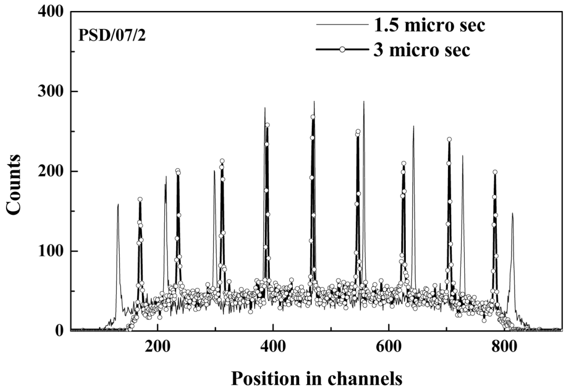

Figure 4. Position spectra showing the effect of amplifier shaping time on the dynamic range.

of PSD no. 5 recorded by shifting the detector from incident beam position by 10 cm along the sensitive length. Shift in peaks is uniform and is ±2 channels. Average position resolution obtained is ∼5 mm. Background counts between the position peaks are low and to an admissible level. Position spectra are also recorded by varying the pulse shaping time. Figure 4 shows two overlapping spectra recorded with pulse shaping time of 1.5 μs and 3 μs. Higher rise time makes the pulse slower and reduces the total dynamic range of the detector. Overall resolution remains the same but the total conversion sensitivity is reduced. The lower shaping time does not give proper linearity as ballistic deficit is increased. With the present detector dimensions shaping time of 1 to 1.5 μs is appropriate.

Change in the input impedance of a pre-amplifier also shows similar behaviour as in figure 4 and with rise in input impedance of a pre-amplifier reduces the dynamic range. The new make of pre-amplifier with very low noise level is used for test set-up and shows very sharp peak shape with a width of ∼3 channels, improving the resolution to 3.5 mm, though the dynamic range is reduced by 40 channels. Thus the resolution is limited by electronics settings and not by the detector hardware

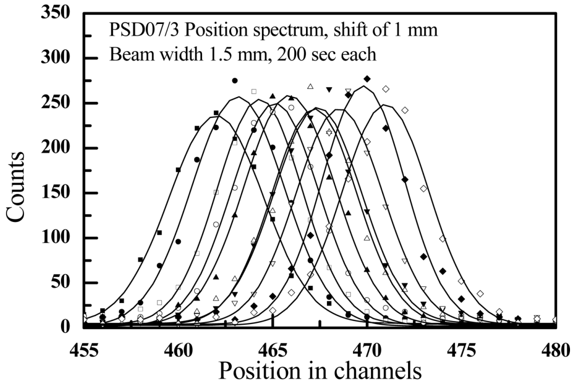

Figure 5. Position spectra of a PSD with collimated neutron beam and shift of 1 mm along the length.

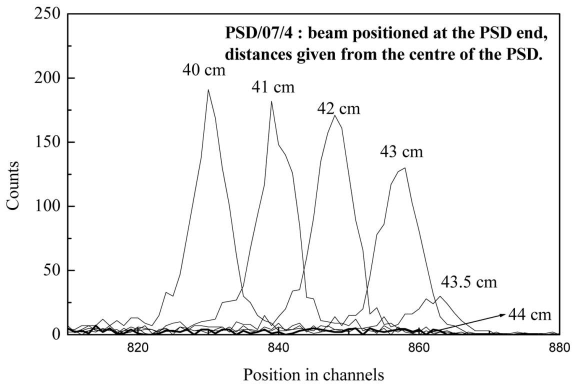

Figure 6. Position spectrum showing end effects on peak width and efficiency at the extreme end of the PSD.

and has further scope for improvement. The position resolution mentioned here is an integral position resolution from the PSD and differential resolution indicates the minimum change in position, resulting in displacement in position spectra. Figure 5 shows the position spectra recorded with a fine shift of 1 mm. It is clearly seen that 1 mm shift results in 1 channel shift. The overall accuracy of readout is 0.95 channels/mm.

PSD is tested for accurate measurement of sensitive length. Figure 6 shows the spectra recorded by incident neutrons at the extreme end of the anode wire. Finely shifted beam shows that sensitive length for use is 840 mm and beyond this length it shows broadening of peak and reduction in peak intensity.

3. Conclusion

Technique of development of PSDs according to the spectrometer requirement is optimized. Detailed primary characterization of PSD helps the user to evaluate the spectrum for sample characterization and subsequent corrections if necessary can be applied.

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