A new fast detection system at the KWS-2 high-intensity SANS diffractometer of the JCNS at MLZ - prototype test

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A new fast detection system at the KWS-2 high-intensity SANS diffractometer of the JCNS at MLZ – prototype test

A Radulescu[1]*, N Arend[1], M Drochner[2], A Ioffe[1], G Kemmerling [1], V Ossovyi[1], S Staringer[1], G Vehres[3], K McKinny[4], B Olechnowicz[4], D Yen[4]
[1]Jülich Centre for Neutron Science (JCNS), Outstation at MLZ, Forschungszentrum Jülich GmbH, 85747 Garching, Germany
[2]Central Institute for Engineering, Electronics and Analytics (ZEA-2), Forschungszentrum Jülich GmbH, 25425 Jülich, Germany
[3]Jülich Centre for Neutron Science (JCNS-1), Forschungszentrum Jülich GmbH, 25425 Jülich, Germany
[4]Reuter Stokes Products, GE Measurement & Control, General Electric Company, Twinsburg, Ohio USA 44087

a.radulescu@fz-juelich.de

Abstract. A new detection system based on an array of ^{3}He tubes and innovative fast detection electronics was designed and produced by GE Reuter Stokes for the high-intensity small-angle neutron scattering diffractometer KWS-2, operated by the Jülich Centre for Neutron Science (JCNS) at the Heinz Meier-Leibnitz Zentrum (MLZ). The new detector consists of a panel array of 144 ^{3}He tubes and a new fast read-out electronics. The electronics is mounted in a closed case in the backside of the ^{3}He tubes panel array and will operate at ambient atmosphere under cooling air stream. The new detection system is composed of eighteen 8-pack modules of ^{3}He-tubes that work independently of one another (each unit has its own processor and electronics). Knowing beforehand the performance of one detector unit and of one single tube detector is prerequisite for tuning and maximizing the performance of the complete detection system. In this paper we present the results of the tests of the prototyped 8-pack of ^{3}He-tubes and corresponding electronics, which have been carried out at the JCNS instruments KWS-2 (in high flux conditions) and TREFF.

1. Introduction

The small-angle neutron diffractometer KWS-2, operated by the JCNS at MLZ, is dedicated to the investigation of mesoscopic structures and structural changes due to rapid kinetic processes in soft condensed matter and biophysical systems. The high neutron flux (Fig. 1), comparable with that of the world leading SANS instruments, which is supplied by the neutron delivery system [1, 2] – cold neutron source, neutron guide, velocity selector, and the possibility to use large sample area, using lenses (for the same resolution as for conventional pinhole mode), enable high-intensity measurements and time resolved studies at tens of milliseconds time resolution [3]. On demand, the instrument resolution can be tuned by varying the wavelength spread between 2% and 20% by using a double-disc chopper with adjustable slit opening [4]. By means of lenses and a secondary high-resolution

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[*] To whom any correspondence should be addressed.

detector (resolution about 1mm) a $Q_{\min}$ down to 1 x 10^{-4}Å^{-1} can be achieved, which, in combination with the pinhole mode, permits the exploration of a continuous length scale from 1nm to one micron [3].

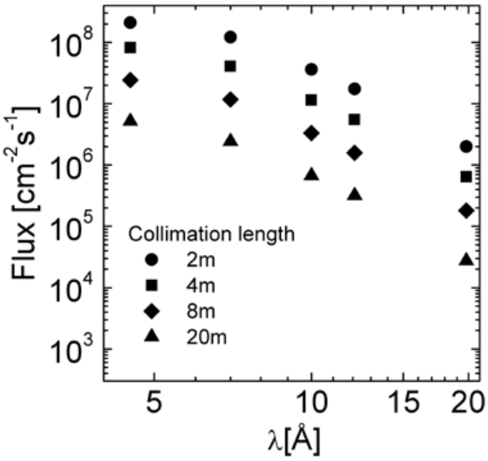

Figure 1. Absolute neutron flux at the sample position as a function of wavelength λ for different collimation lengths L_C and full beam-size (50mm x 50mm), as provided by the neutron guide.

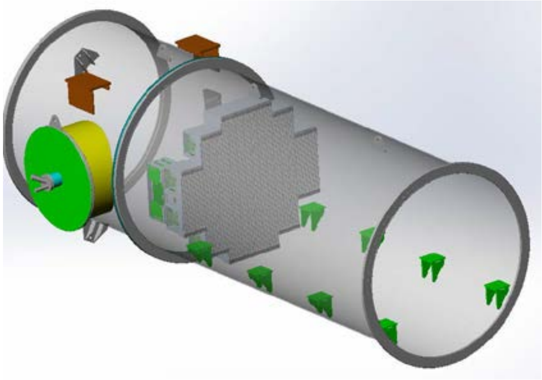

Figure 2. Detector upgrade proposal for KWS-2: the diameter of the vacuum tank is 1.40m.

The main detector of the instrument, which was in use until the summer of 2015, was a Anger camera based on an array of 4x4 ^{6}Li glass scintillator and 8x8 photomultipliers [5] and provided a 60x60cm^2 active detection area with a space resolution of about 7mm. The limited count rate at 10% dead-time (ca. 150kHz), the gamma sensitivity and the inhomogeneous dead-time over the detection area for the cases of samples exhibiting strong scattering in the forward direction, were a drawback, especially for investigations on small soft-matter and biological molecules that typically deliver at high *Q* very weak scattering signal above the buffer or solvent level, and thus demand very high neutron intensity and a high stability in time of the pixel response. In the end of 2013 it was decided to replace this detector with a new detection system with a performance that enables the optimal use of the high flux of the instrument (up to $2x10^8$ n cm^{-2} s^{-1} are available on the sample). A collaborative work between JCNS and GE Reuter Stokes Inc. was started, with the main goal to install at KWS-2 a new detection system consisting of an array of position sensitive ^{3}He tubes with a larger active area (towards 1m^2) and an innovative rapid electronics, capable for measuring a count rate of 1MHz, or even higher, at 10% dead-time. The new detector should have a modular structure consisting of several 8-pack units of ^{3}He tubes (8mm) that should be combined together at appropriate number and lengths, so as to maximize the active area by filling completely the cross-section of the KWS-2 tank (Fig. 2).

The high-voltage and read-out electronics should be mounted in a closed case at the backside of the ^{3}He tubes panel array and should operate at ambient atmosphere under cooling air stream. As the new detection system will be composed of many 8-pack units that will work independently of one another (each 8-pack unit has its own processor and electronics), the performance of one detector unit and of one single tube are needed to be known beforehand. This helps for tuning and optimizing the performance of the full system by knowing the expectations regarding the maximal performance of several similar independent units that will work in parallel while assembled together into the complete detection system.

In this paper we present the results of the tests of one prototyped 8-pack unit of ^{3}He-tubes and corresponding electronics, which have been carried out at the JCNS instruments KWS-2 (in high flux and vacuum conditions) and TREFF.

2. Technical and experimental details

The prototype 8-pack detector module consisted of eight ^{3}He tubes of a diameter of 8mm and an active length of 822mm, two preamplifiers, two high-voltage (HV) modules and a digital processing board (platform processor). The ^{3}He pressure is 12.6 bar, which corresponds to an efficiency of 85% for λ=5Å [6]. An air box containing an Ethernet router (Hirschman) and the mechanical (cooling lines) and electrical (wired Ethernet cabling for signal and power) interfaces between the 8-pack and the air box and router were attached to the prototyped detector module.

At KWS-2 (Radulescu et al., 2012) the detector module was placed in the vacuum tank (2x10^{-2} mbar), in an out-of-direct beam position. Two airlines (one supply, one exhaust) were connecting the air box with the outside of the vacuum tank and cooling air at a flow rate of 800 l/min and humidity less than 5% were provided to the air box and further to the 8-pack electronics. One optical Ethernet cable (for signal) and one power cable were routed through the exhaust airline from the air box to outside the vacuum tank and further to an external router (Hirschman) and power supply (Toellner). The two Hirschmann routers (one in the air box, one outside the vacuum tank) were capable of supporting high speed data (1Gbit), power-over-Ethernet (PoE) and precision time protocol (PTP).

At TREFF the detector module was placed in air, having further the cooling lines, the Ethernet and power cables and the external router connected to it.

All data have been collected in 1024 channels (pixels) over the length of each tube, which is the maximum resolution supported by the detector electronics.

Measurement of count rate and stability of the pixel response were carried out at KWS-2 using a incoherent scattering Plexiglas (PMMA) standard sample that provided an flat homogeneous scattering pattern on the detector. The detector was placed at 1m and 2m after the sample and various collimation lengths (8m, 4m and 2m with a 50x50mm^2 entrance aperture) and beam sizes (sample aperture between 8x8mm^2 and 25x25mm^2) were used for varying the neutron intensity on the sample, and thus the count rate on the detector. For determining the dead time and the count rate behavior an almost dead time free fission chamber (LND) was mounted after the sample in an out of detector view position [3], in order to collect in parallel the incoherently scattered neutrons on the sample. The check of the stability of pixel response involved conducting of repeated measurements (30 minutes each) at constant intensity conditions and over a long time period during day and night, in order to have variable EMV and neutron background environment dictated by the regular activities taking place around the instrument. Different count rates between 4 and 16cps per pixel have been tested.

Measurements of linearity, resolution and stability of resolution were carried out in direct beam at TREFF using a narrow vertical slit (1mm x 10cm) and moving the detector in beam along its long axis with constant step (2cm) that allowed the local illumination of all eight tubes at once and the scanning along the active length of tubes.

3. Results and discussion

3.1. Flood test

Fig. 3 shows the intensity profile on each tube for homogeneous scattering on the 8-pack provided by the incoherently scattering Plexiglas sample at a count rate of about 4000cps on each tube. A narrow Cd stripe (5mm) with a thickness of 0.5mm was mounted in the middle of the 8-pack, across all tubes, with the purpose of adjusting the pixels across the 8-pack by using the sharp drop in the intensity profile provided by the Cd-mask. The weak waviness observed for some tubes is due to small imperfections along the anode wire and turned out to be stable in time and over a broad range of count rates, thus correctable by applying a sensitivity calibration.

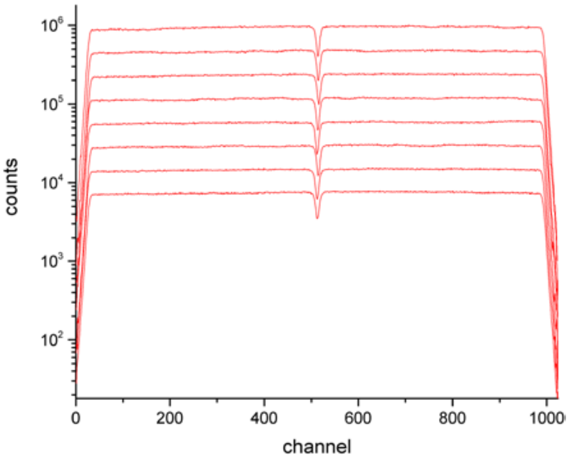

Figure 3. Intensity profile of the detector flood (homogeneous illumination) for each ^{3}He tube of the 8-pack; the results are scaled up with a factor of two, for clarity.

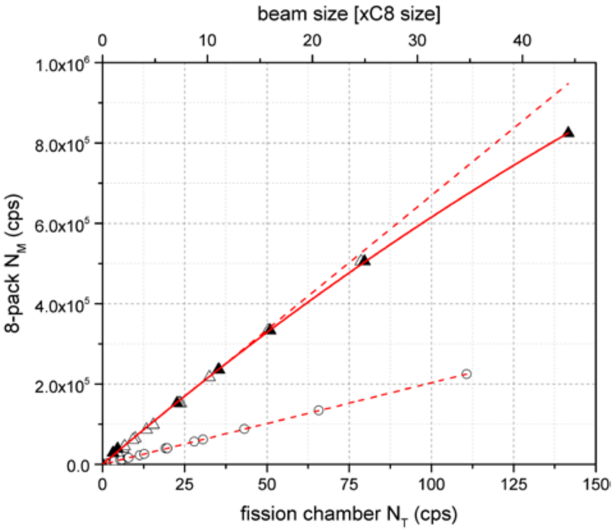

Figure 4. Dead time measurement on the ^{3}He 8-pack positioned at 1m (triangles) and 2m (circles) after the sample; the results are presented versus the intensity measured in parallel with a fission chamber (open symbols) or as a function of beam size (filled symbols).

3.2. Dead time and count rate

Fig. 4 shows the measured count rate N_M on the detector at two sample-to-detector distances (L_D=1m and L_D=2m) versus the count rate N_T given by the fission chamber [3], which is proportional to the flux of incoherently scattered neutrons. Additionally, the measured intensities at L_D=1m are shown versus the beam size [7, 8], which was varied by changing the collimation length and size of source (entrance) and sample apertures. Therefore, the beam size is expressed in multiples of standard beam-size, which, for the old scintillation detector at KWS-2, it was considered for the collimation length L_C=8m and the aperture sizes of 30mm x 30mm (source) and 8mm x 8mm (sample). By considering a homogeneous beam, the intensity is proportional to the aperture sizes and squared ratio between collimation lengths. The full line in Fig. 4 are the data fitting with the paralyzable model [9], and the dotted lines are linear functions. No deviation from the linearity is observed for count rates as high as $3x10^5$cps for the whole 8-pack. At higher count rates deviations from the ideal linear behavior due to dead time are observed. The dead time τ is found 70ns, and corresponds to a 10% loss at around N_M=700kHz. Given that each 8-pack module has its own platform processor, it is expected that in an ideal case, a larger 2D detector consisting of many 8-packs, like that shown in Fig.2, will have a count rate that will scale with the number of 8-packs. Thus, with the optimized data transfer and storage, several MHz at 10% dead time are expected in this case.

3.3. Stability of the pixel response

In order to check the stability of the pixel response over a long time, long series of similar Plexiglas measurements were carried out at constant count rate. The stability was checked by dividing results obtained on two similar measurements performed at different time and calculating the standard deviation of the ratios. Typically, 24 measurements each of 30 minutes were performed during the day and during the night time, when the EMV and background conditions around the instrument were different. The procedure was repeated for low and high count rates. Fig. 5 presents the ratio between two similar measurements on tube No. 6 carried out at two count rates, 4cps per channel and 15.5cps per channel. In both cases the results it is around 1 along the entire tube length (end channels were excluded due to the high uncertainty) and the standard deviation of the ratios lies within statistical uncertainty of the measurements.

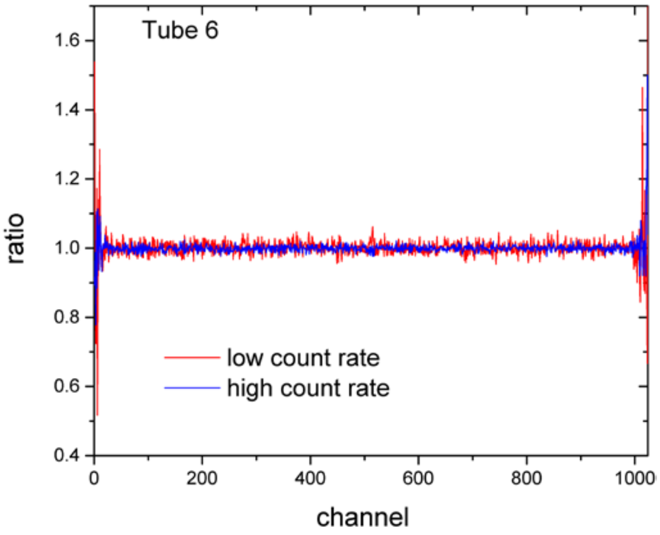

Figure 5. The ratio between two similar measurements with constant count rate performed at different times; two count rates were tested.

3.4. Position calibration and linearity

The position resolution was tested along the anode wires (with a 2cm step) by using a Cd-mask with 1mm slit which stretches across the entire 8-pack (Fig. 6a). Thus, all eight ^{3}He tubes were illuminated at once. The position linearity was tested (Fig. 7b) and the fit function of the measured positions to the actual positions was y=(1±0.000471)x+(0.525±0.1088). The linear correlation coefficient was 1.024, which showed a good linearity.

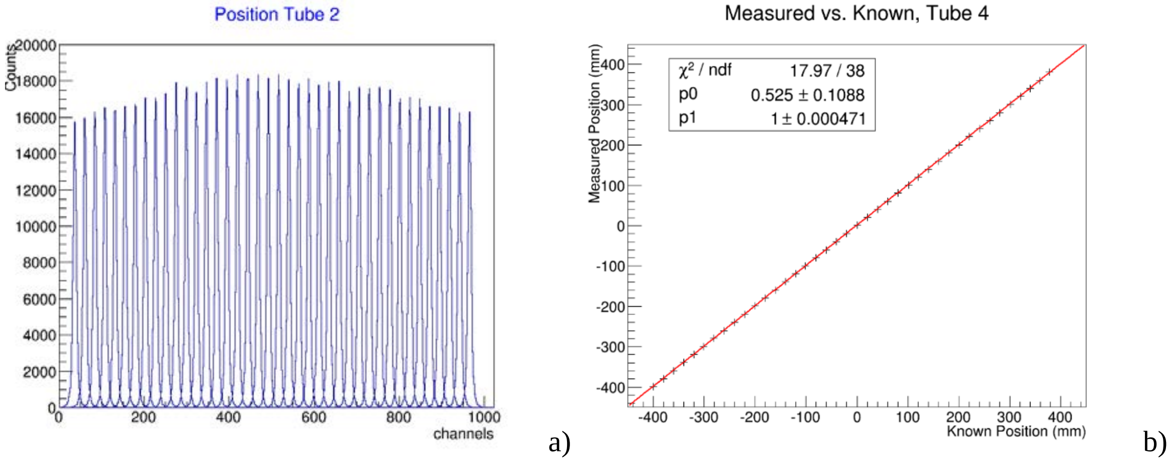

Figure 7. Example of results of the scan measurement along the anode wire (a) and of the position reconstruction (b).

3.5. Position Resolution

Gaussian fit to peaks measured along the tubes by using the 1mm slit (Fig. 7a) delivered the position resolution (Fig. 8), which is better than 8mm for all eight tubes. By repeating the measurement at different times it was found that the position is stable within 0.06mm RMS.

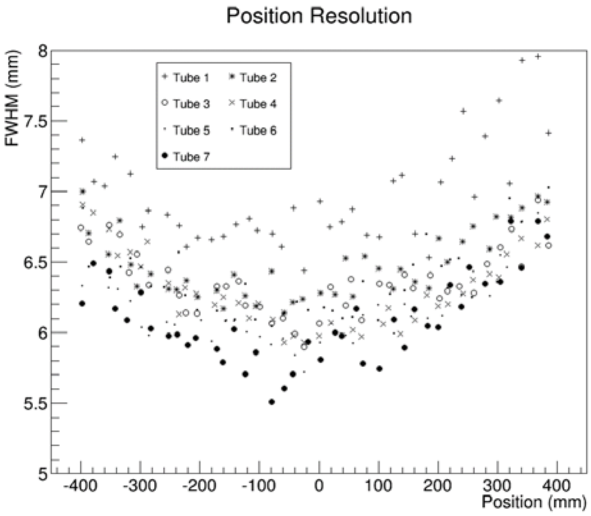

Figure 8. Position resolution along the anode wire for all eight ^{3}He tubes in the 8-pack

4. Summary

A new fast detection system is planned for the high intensity SANS diffractometer KWS-2, which is operated by the JCNS at MLZ. The new detector should consist of 144 ^{3}He tubes, which will be grouped in 8-packs that will work in parallel, each 8-pack having its own microprocessor. An 8-pack prototype was produced and was tested at KWS-2 (in high flux conditions) and TREFF instruments of JCNS, in order to learn about the capabilities of the new detector and how tuning and maximizing the performance of the complete system can be achieved.

A summary of the test results on the 8-pack prototype is presented in Table 1. It is thus expected that the new detection system will show a high stability of the pixel response and position, a position resolution better than 8mm and a high count rate (several MHz) at 10% dead time.

Table 1. Parameters (targeted and measured) of the ^{3}He fast detector prototype for KWS-2

Parameter	**Target**	**Measured**
count rate (tube)	28000 cps	~90000 cps
count rate (8-pack)	224000cps	~720000cps
position resolution	<8mm	<8mm
position stability (RMS)	≤ 1.5mm	< 0.06mm
position accuracy / linearity	–	1mm
pixel rate stability	<< 10%	<0.4% within statistical uncertainty

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