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IP092 DEVELOPMENT OF A NEUTRON-SENSITIVE ANGER CAMERA FOR NEUTRON SCATTERING INTRUMENTS

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ABSTRACT

To increase the resolving power of neutron scattering instrumentation for crystalographic aplications a new high resolution neutron-sensitive Anger camera systems was developed at the Spallation Neutron Source facility (SNS) at Oak Ridge National Laboratory. These cameras have 1mm position resolution over the entire 152 x 152 mm^2 active area. 90% effficiency for thermal, 0.025 eV neutrons, and a 5 x 10^4 n/s rate capability. Two of the instruments, TOPAZ and MANDI are designed for 48 cameras. These large arrays of high resolution Anger cameras should make it possible to study crystals with unit cells up to 60 Å and crystalline proteins with up to 10^6 atoms. The camera design and preliminary performance data are presented in this paper.

1. Introduction

A new high resolution, high rate Anger camera [1] has been developed to support crystallographic studies at high powered neutron scattering facilities. This Anger camera (Fig. 1) was designed to provide the highest possible position resolution since this is needed to study large unit cells, and high rate capability to record data from samples with a large number of Bragg peaks.

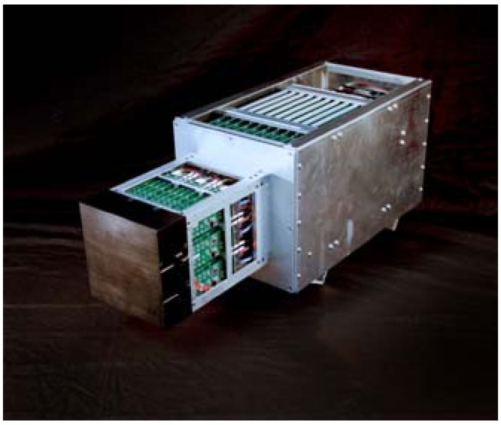

Fig. 1. Picture of a TOPAZ high-speed neutron-sensitive Anger camera module.

For the single crystal diffractomter instrument (TOPAZ) at the Spallation Neutron Source (SNS) this camera is needed to enable the development of new materials. One example is single crystal studies of relaxation processes. These distort the crystal lattice resulting in unique material properties. Another example is increasing the capability to determine the structure of proteins in crystal form containing up to 10^6 atoms per unit cell [2].

2. Detector Details

The design of the SNS neutron Anger camera incorporates the use of standard neutron scintillator, GS20 [3], which has been used in other neutron Anger cameras [4]. At 2mm thickness, the detection efficiency is 90 percent for thermal (0.025 eV) neutrons. Requirements for 1mm resolution places design limits on individual PSPMT sensors. For a typical Anger camera, the position resolution is limited to 10% of the PSPMT size which implies that for 1mm, the tube must have an area less than $1cm^2$ and a 15 x 15 cm^2 camera would have in excess of 200 tubes. To overcome this complication the new Anger camera system uses position sensitive multi-anode photomultiplier tubes (PSPMTs). To optimize the packing density the camera uses 9 PSPMTs in a 3 x 3 array. The Hamamatsu H8500 was selected because it has an 89% effective area ratio and is tileable with minimal gaps. This PSPMT has 64 anodes in an 8 x 8 array, each slightly more than 6mm across to provide 49 x $49mm^2$ coverage [5]. The camera has 576 individual anodes which makes it possible to achieve 1mm resolution.

2.1. Development Challenges

To realize such a device several challenges had to be met:

1. Gain matching individual anodes
2. Readout for 576 pixels per camera at high speed.
3. Bridging 4mm dead space between individual PSPMTs
4. Fast image processing to enable high count rate.

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2.2. Front End Electronics

To enable the higher pitch design, two strategies are implemented: the individual pixels were gain-matched in hardware, which enabled the anode pixel signals to be summed in 2 dimensions. This is diagrammed in Fig. 2.

To reduce the number of electronics channels the outputs of the rows and columns within the PSPMT were summed to give 16 rather than 64 signals. For the 9 PSPMT array this represents 9 x 16 = 144 outputs. Tests showed that the signal to noise ratio was not significantly degraded by summing. This was due to the high light levels of the neutron scintillation events in GS20.

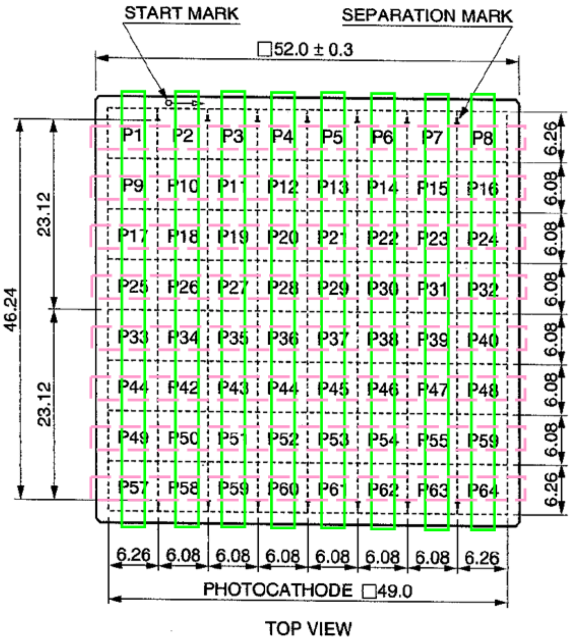

Fig. 2. Summing strategy for pixels. Green columns are summed to readout horizontal (x) position information. Rose colored rows are summed to readout vertical (y) position information.

The PSPMT signal from a scintillation event is a current pulse with a 70 ns width. The Linear Technologies LT1806 op-amp [6] is used as the preamplifier stage due to its high bandwidth and high output. This enables signals from each PSPMT anode to become a fast voltage pulse that follows the current profile with a nanosecond scale time response. An in-house system has been built to gain-match each preamp to the corresponding PSPMT anode pixel. The preamplifier gains are tuned by selecting the appropriate feedback resistors. Gain matching within 5% is achieved.

With voltage signal from each anode are split to x and y summing circuit stages. The sum is achieved by inputting each set of 8 pixel preamp outputs to a second fast op-amp voltage amplification stage. This stage is designed with the LT1806 op-amp configured as a fast voltage amplifier. This maintains the anode pulse integrity for accurate summing. Again, 64 anode signals are converted to 8 x sums and 8 y sums. Each of 16 outputs from each of 9 PSPMTs are integrated, then, digitized with a 10-bit ADC. Each of 144 signals is provided a time stamp set by the time of the pulse that has triggered the integration. Integration proceeds for 550 nanoseconds, providing optimum signal to noise. At periods of high-rate multiple neutron events can be buffered. The time stamp has a 50 ns resolution. Absolute resolution is estimated to be 100 ns for each neutron event. Each module can process 5 x 10^4 neutron events per second.

2.3. Optics

In parallel with the electronics development the optics needed to be optimized to provide a uniform and continuous response over the entire field of view (FOV). The main issue was the gap between the anodes of adjacent PSPMTs which needed to be imaged in a continuous way. However, it was not immediately obvious how this could be achieved. In Fig. 3a is represented the traditional concept for an Anger camera design. In Figure 3b, is shown the cross-sectional configuration of new optics with traditional Anger camera using segmented tubes.

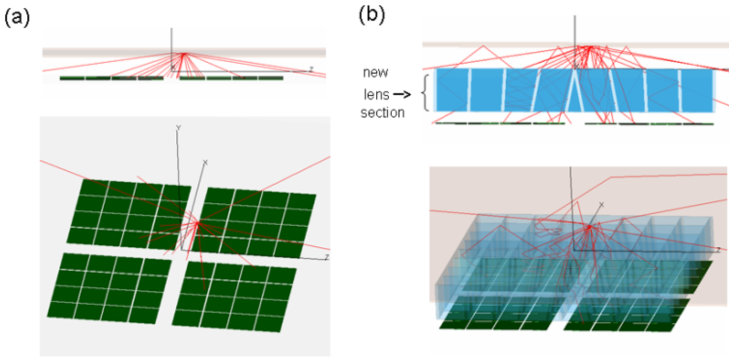

Fig. 3 Two optics approaches. (a) Traditional (b) New type of optics for segmented tubes guiding scintillator light from a regular distribution on the scintillator to an irregular distibution of anode pixels on the tiled PSPMT array.

Fig. 3 is a simulation of photon traces. It illustrates how light is lost in gaps between segmented PSPMT elements where no detection surface can exist with the traditional neutron Anger camera optics approach. In Fig. 3(b) the new approach developed at SNS demonstrates how much more light is recovered for imaging from a scintillation event.

In an Anger camera the position of the neutron event is determined by fitting the light cone from the scintillator with either Anger logic or an empirical equation. During tests with the traditional approach it was found that the fitted position did not track the event position across the gap region. The fitted position could jump in an unpredictable manner. After introducing the lens the behavior improved greatly, but an additional refinement was needed before 1mm resolution could be achieved in the gap. In Fig. 4 the upper left image shows a regular arrangement of the reflecting surfaces in the lens. This lens maps a regular x,y array on the scintillator to the irregular anode locations on the PSPMTs In the lower left image the reflecting surfaces have been adjusted to improve the behavior. On the right simulations show the improvement in tracking.

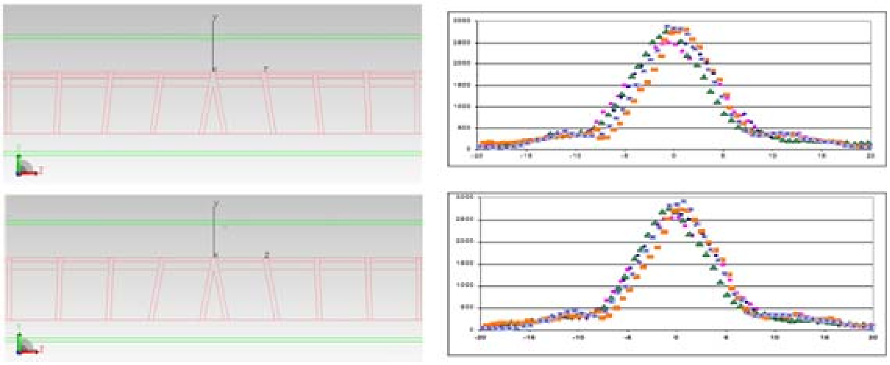

Fig. 4. Left illustration: Reflective surfaces are adjusted to minimize light cone shift. .Right Illustration; Plot of simulated light cones: the lower series of light cones are shifting less that the upper graph. This design is used in TOPAZ. The resulting light cone is well represented analytically with 2 gaussians.

To optimize the position resolution for a conventional Anger camera the light cone should cover approximately 3 anodes. In this design this was achieved by adjusting the thickness of the optics package.

2.4. Flat Field Response Correction

After the optics were optimized to correct the gap light cones, test mask images still contained systematic destortions. These distortions are caused by a bias in the optics which tends to shift the fit position to the center of an anode. These shifts are typically on the order of 0.5 mm, but even these slight shifts can dramatically affect the appearance of the image. To correct the distortions flood pattern neutron images were aquired and then smoothed. This process is justified because the scintillator is uniformly efficient and the counts per unit area should be consistent for a flood pattern, and the neutron signals lie in a well defined photopeak. [7], [8]. Typically 20 million events are accumulated and then processed as rational numbers before binning.

3. Position Calculation

Because the optics package is unique, with discrete reflecting surfaces, the position determination is a multi-step process. First the light cone needs to be measured. This is done by stepping a slit across the FOV in fine increments to build up the light cone. The light cone is then determined by a least-square fit to a 2-gaussian function. The imaging process is demonstrated in Fig. 5 using a flood pattern. By tradition, the first step for imaging is performing a least-square fit to this 2-gaussian function that would result in a recognizable image. However, the lens that is necessary to bridge the gaps between each PSPMT does not respond this way. Rather, the least-square method is thought of as a necessary part of the transformation process to best prepare raw data from the Anger camera to image deterministically, once the flat-field process is performed. While the image in Fig 5a appears graphically distorted, it is actually optimized for proceeding to the flat-field process. In Fig. 5b the flat-field process has been applied. The optimization involves using a fitting function that is more akin to an optimized transform fitting function, as opposed to an imaging function

Thus, the detector is first exposed to a neutron flood pattern. The anode responses are least-square fit to a transform function. This is the result shown in Fig.5a. The image is then corrected using the flat field correction, which produces the image in Fig. 5b. This can be seen as a transformation from one x,y grid to a corrected grid. Once this 2-dimentional transformation is defined then the detector is ready to take data. Neutron events are fit using the transform fitting function derived from the measured light cone.

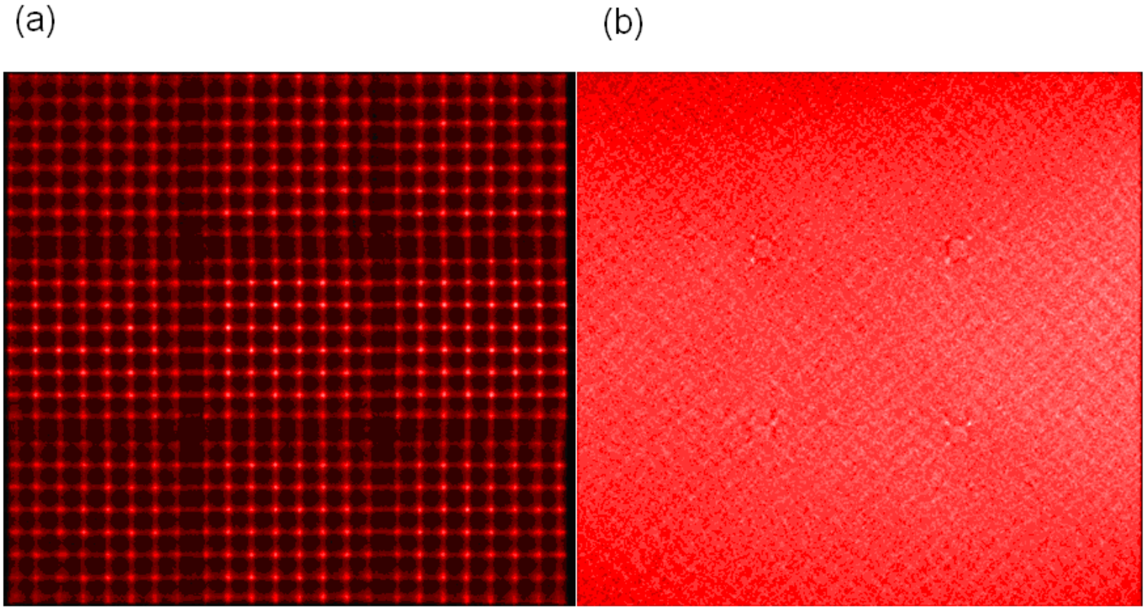

Fig. 5a) Uncorrected flood pattern data, 5b) Flood pattern data after uniformity correction

Provided in Fig. 6 are neutron images from a TOPAZ module of a test mask with 0.75mm wide slits. This test was performed over the gap regions between segmented PSPMTs in order to demonstrate the uniformity of the images. Shown are least-square-fit image data before flat-field correction, and after flat-field correction. In Fig. 7 is the spatial resolution result corresponding to Fig. 6.

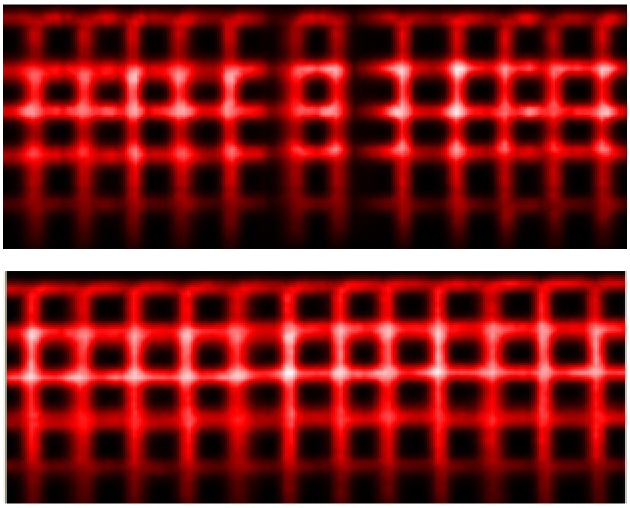

Fig. 6 Resolution and image uniformity results using test mask and a moderated Cf-152 source. After flat-fit process uniformity and resolution are fully recovered.

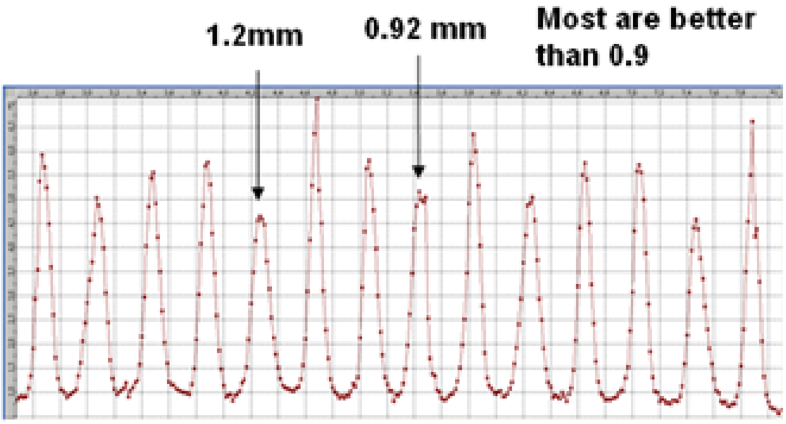

Fig. 7 Horizontal cross section through the flat field corrected figure 6. Average spatial resolution under 1mm.

The flat field correction process has been developed and now is implemented on 2 instruments using the Anger camera, SNAP and TOPAZ. The same flattening algorithm is also used on the Brookhaven He-3 multi-wire imaging detectors.

4. Data Acquistion

Signals from 9 PSPMTs can be processed at 50kHz per module. The analog signals for the 16 outputs from the summed PSPMT pixels are transmitted by LVDS drivers to an Anger read out card, AROC. On the read out card the signals are split with one branch going to a discriminator and the other to a delay and integrator. When any of the discriminators trigger, all 144 channels are integrated. Baseline and integral values are recorded with 10-bit ADCs. The card can be calibrated by an automated routine that corrects for baseline shifts. A signal from a DAC is used to set the integration offset to prevent the voltage from reaching ground. This is done using an on board FPGA[9]. The ADC values and the time stamp for all 16 channels can be buffered. The same time stamp is then daisy chained to 9 individual AROC boards.

Position calculations are done with a FPGA. The FPGA performs the least-square fitting routine to reduce the 72 x and 72 y integrals to x and y positions, respectively. The positions are stored in 5 significant figures, and are not binned until after the flat field correction is complete. At present this correction is done on the preprocessing computer and data server. The data acquisition server is able to perform live calibration of the integration electronics of the 9 AROC modules. It may also begin data acquisition on any number of neutron Anger camera modules. TOPAZ has room for 48 modules. In the short term, 25 neutron Anger camera modules will be installed.

5. Conclusion

The neutron Anger camera described here represents a new strategy for meeting the challenge for a high resolution and high speed real-time imaging technology needed for single crystal neutron diffractometry instruments. The camera uses GS20 scintillator and has an active area of 152 x 152mm^2 Position sensitive photomultiplier tubes are used to reach the goal of 1mm position resolution, but before these tubes could be used, a new optics package needed to be developed. In addition a high rate electronics scheme was employed to enable rates as high as 50k n/s per camera. Finally, new fitting software and flat field correction routines were developed. The camera has met the rate and resolution goals and 23 are in operation at the SNS. Research will continue to improve the position resolution and achieve sub-mm resolution.

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