Flat Panel PMT for photon emission imaging

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Abstract

Over the last 15 years Hamamatsu has been developed two generations of Position Sensitive Photomultipliers (PSPMTs). The first and the second generation were based on mesh dynode and metal channel dynode respectively. In this paper, we present the first results obtained from the last generation: Hamamatsu H8500 Flat Panel PSPMT. The active area is increased to 2 in. with minimum peripheral dead zone and thickness down to 12.5 mm. Measurements were addressed to nuclear medicine for single photon imaging. To this aim, we have taken into account two different electronic readout: resistive chain and multi-anode readout (64 channels). To evaluate the imaging performance, the Flat Panel PSPMT was coupled to CsI(Tl) and NaI(Tl) scintillation arrays with pixel size of 3 and 2 mm, respectively. Images of CsI(Tl) array, obtained by multi-anode readout, showed an improvement of spatial resolution, from 1.2 to 0.8 mm, and of position linearity response. On the contrary for NaI(Tl) array, no relevant image differences between two system readout were obtained.

\( \text{PACS: 87.62; 87.59; 29.40.M} \)

Keywords: PSPMT; Scintillator array; Single photon imaging

1. Introduction

Over the last 15 years Hamamatsu two generations of PSPMTs have been developed. The first generation was based on mesh dynode and the tubes were characterized by a wide intrinsic charge spread, large active area (up to 5 in. diameter) [1–3] and by a total volume comparable with standard PMT. The second generation is based on metal channel dynode [4] for charge multiplication with an intrinsic spread of charge better than 0.5 mm. Furthermore, it is characterized by metal housing that allows a very compact size (about 1 in.\textsuperscript{3}) with an active area of 22 mm \times 22 mm. Over the recent years, some research groups have realized new large area compact gamma cameras (up to 7 in. \times 8 in.) based on PSPMT Hamamatsu R7600/C8–C12 [4]. They were assembled in array...
and coupled to scintillating arrays, following the original idea developed by Pani et al. [5]. Such detectors have the advantage of very large detection area, compact size and light weight. Their main disadvantage is a substantial ineffective area resulting from PSPMT closely assembled (30% dead zone). Inside dead areas, the spatial resolution, the camera uniformity response and the energy resolution are worsened. In this paper, we present the first results obtained from the last generation: Hamamatsu H8500 Flat Panel PMT [6]. This tube is based on the same technology of charge multiplication i.e. metal channel dynode. The active area is about 2 in. with minimum peripheral dead zone (1 mm) and with 12.4 mm thickness. The Flat Panel PMT seems to have high potentials in nuclear medicine imaging because it can be assembled in array covering large detection area with an improved effective area up to 97%. Working alone the larger active area with respect to R7600 series is much more suitable for a number of applications in nuclear medicine like imaging probe and small animal imaging. The only disadvantage seems the thicker photocathode glass window (3 mm) needed from the larger active area. On the contrary it allows larger anode pitch (6.5 mm) for light sampling reducing to 64 the total number of anodes. Measurements presented in this paper are addressed to nuclear medicine for single photon imaging. To this aim, we have taken into account two different electronic readout: resistive chain based on Anger Camera principle and a multi-anode readout (64 channel). To evaluate the imaging performances, Flat Panel PMT was coupled to a number of scintillation crystal arrays as CsI(Tl), and NaI(Tl), with pixel size of 3 and 2 mm respectively.

2. Equipment

The sample of H8500 Flat Panel PMT is shown in Fig. 1, where its compactness is clearly visible.

The external size is $51.7 \text{ mm} \times 51.7 \text{ mm} \times 15.4 \text{ mm}$ (12.4 mm final goal); the photocathode is bialkali and 12 metal channel dynode stages are used as electron multiplier. $8 \times 8$ matrix anode (64 channels) is used for position sensitive function. The peripheral dead zone is reduced down to 1 mm (0.5 mm final goal), so the overall active area is $49.7 \text{ mm}^2$.

The CsI(Tl) and NaI(Tl) scintillating arrays were manufactured by Hilger Analytical and Bicron Crysmatec respectively. The pixel size is $3 \times 3 \text{ mm}^2$ for CsI(Tl) and $1.8 \times 1.8 \text{ mm}^2$ for NaI(Tl) array respectively. CsI(Tl) $15 \times 15$ array and NaI(Tl) $24 \times 24$ array have the same $48 \times 48 \text{ mm}^2$ dimension. NaI(Tl) array has an aluminum housing and 3 mm thickness of glass window. Each CsI(Tl) element of the array is coated in a white diffusive epoxy reflector; on the contrary white powder is used to optically insulate NaI(Tl) individual, giving a total dead zone of 0.200 mm. They are sufficient to provide complete optical isolation between neighboring crystals. The thickness and pixel size of scintillation crystals were specifically chosen for clinical applications in order to obtain a good sensitivity by matching standard collimator hole size. NaI(Tl) and CsI(Tl) crystals have 6 and 5 mm thickness allowing an intrinsic detection efficiency of 80% and 90%, respectively, at 140 keV photon energy. Two methods of read out are compared in this paper. The first is the conventional resistive-divider technique (see Fig. 2).

Here, the readout electronics consists of two resistive chains [7] connected to the $X$ and $Y$ wires, respectively. Four preamplifiers, mounted close to the tube, read out the four ends of resistive chain.
The pulses were acquired in list mode through a multi-parameter FAST MPA/PC consisting of a card installed in a Pentium PC. The second method uses a ‘multi-anode’ read out technique in which, the charge on each anode is individually read out and digitized. The subsequent position calculation is performed in software. The READ system, developed at Southampton University, is capable of reading the anode values from the FlatPanel PMT and calculating the event position at rates in excess of 1000 events/s. The READ system electronics consists of custom-built 5in. diameter processing board, which carries the HX2 multi-channel amplifiers and the control logic. The HX2 [8–10] chip is a 16-channel integrating amplifier array with data storage and multi-plexed outputs. The board operates on the principal of continually repeating, fixed length integration periods. The serial output from the HX2 board is subsequently read by a 1.5 MHz National Instruments AT-MIO Analogue to Digital Converter (ADC) mounted in host PC. In order to analyze the intrinsic characteristics of the detector $^{57}$Co point source was used. The characterization of the PSPMT was also performed by flood-field irradiation measurements by free $^{57}$Co source at a distance of about 5m far from the detector.

### 3. Results and conclusions

#### 3.1. Resistive readout

The scintillating arrays were coupled to the Flat Panel PMT and irradiated by a $^{57}$Co source. Fig. 3 shows the image obtained by flood irradiation of CsI(Tl) array. Image spots represent crystal array elements, demonstrating the capability of the tube in determining scintillation light distribution centroid with a precision better than pixel side (intrinsic spatial resolution).

Comparing raw image cross-sections, shown in Figs. 3 and 4 it is clear how NaI(Tl) produces better spatial resolution values with respect to CsI(Tl). In fact NaI(Tl) array carries out spatial resolution values of $1.0 \pm 0.2$ mm in the crystal central portion. On the contrary CsI(Tl) array shows $1.2 \pm 0.1$ mm values at the same detection area. Near the boundary of detection area (3–4 peaks at the right and the left of cross-sections) spatial resolution values are worsened for both arrays ranging between 1.2 and 2.2 mm and between 1.4 and 3.4 mm for NaI(Tl) and CsI(Tl).
crystal, respectively. Roughly the FWHM of peaks is constant while position linearity changes near PSPMT boundary area, as it is clearly visible from the peak-to-peak progressive distance reduction down to peak overlapping. This effect is intrinsically produced by light distribution truncation at PMT boundary that involves a wrong position centroid by resistive chain in one direction only. Furthermore, additional position distortions are probably introduced from a poor anode gain uniformity response and from higher noise introduced by two anodes. In fact, resistive chain response and consequently spatial resolution are strongly dependent on PMT signal-to-noise ratio. Comparing the flood field image cross-sections along one axis obtained from Flat Panel PMT and from R7600–C12 2 × 2 PMT array coupled to the same NaI(Tl) array, respectively, it is clearly visible how spatial resolution values improve in the center of each tube while they are worst in the center of imager (internal dead zones) and at each PMT boundary (see Figs. 4 and 5).

Spatial resolution values shown in Fig. 5 are 0.7 ± 0.1 mm FWHM within each PMT active area, 0.9 ± 0.1 in the middle of the camera and between 1.1 and 2.5 mm at camera boundary. In this case spatial resolution values are more affected by position non-linearity generated from the presence of dead zones in the middle of camera. In such zones also relative energy resolution values are worsened down to 20%. On the contrary into the PMT active area energy resolution shows values comparable with the analogous ones obtained by Flat Panel PMT (13 ± 1% FWHM). In conclusion Flat Panel PMT shows a more uniform position response and spatial resolution values comparable with mean values obtained by R7600–C12 2 × 2 PMT array. It is a good result taking into account the different total thickness of optical guide, 4 and 6 mm for R7600 and Flat Panel, respectively.

3.2. Multi-wire read-out

The results obtained using multi-wire read-out system are shown in Figs. 6 and 7, for CsI(Tl) array. An impressive improvement in the spatial resolution and position response for CsI(Tl) array can be seen, comparing with the analogous ones
obtained by resistive chain. It is evident the strong improvement of spatial resolution (0.8 ± 0.1 mm) in the PSPMT central portion and the more uniform position response that allows the identification of all pixel of the scintillation array. In particular near the boundary of the tube the worst spatial resolution values resulted between 1.1 and 2.5 mm. This strong enhancement of Flat Panel PMT response was also probably due to the disconnection of two noisy anodes as it is clearly visible from the two holes in the flood field image obtained by multi-anode read-out. Such image performance improvement did not result from NaI(Tl) array, where spatial resolution values ranged between 0.9 and 1.1 mm in the central detection area. A slightly more uniform position response was obtained in particular near PMT boundary where crystal pixels were better identified. The different behavior of the two crystal arrays could be justify from the additional signal noise produced by resistive chain that influences more or less spatial resolution and linearity response depending on scintillation light output. In fact, in spite of CsI(Tl) array, NaI(Tl) shows a light output three times more intense. It means that NaI(Tl) images are a better signal to noise ratio and CsI(Tl) images are dominated by resistive chain noise. However, utilizing multi-anode readout, Flat Panel PMT shows better spatial resolution values and position response with CsI(Tl) array demonstrating how the NaI(Tl) higher light output does not compensate the wider light distribution generated by the additional crystal glass window.

Acknowledgements

We thank Hamamatsu Photonics for providing us with the sample of H8500 PSPMT. We greatly appreciated the faithful collaboration of Yuji Yoshizawa and Miles Nakamura.

References