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Performance of a New Position Sensitive PMT

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Abstract Position sensitive photomultiplier tube (PS-PMT) represents a technological improvement in the development of new concept gamma cameras based on the principle of a single tube. Very recently, a new compact PS-PMT, Hamamatsu R7600-C12, has been developed. The PS-PMT has 11 stages of metal channel dynodes and $6(x)+6(y)$ crossed plate anodes in a 25.7mm square × 20mm high metal can package, where the effective area is $22\times22\text{mm}^2$. Tests of spatial resolution, spatial linearity, gain uniformity and timing resolution were carried out by coupling the PS-PMT to the LSO an GSO scintillators in terms of applicability to Positron Emission Tomography (PET) system. High spatial resolution of about 1.4mm is obtained by using LSO crystals coupled to the PS-PMT, and the good spatial linearity, gain uniformity and timing resolution are also obtained.

Key words position sensitive photomultiplier tube, detector, positron emission tomography

1 Introduction

PS-PMT have been used in a number of applications such as particle physics, materials science and medicine, most notably in the PET detector and have a certain advantages in terms of spatial resolution over using an array of standard PMT for position decoding. Up to present, a number of PS-PMTs have been developed and applied to PET system dedicated to animal studies[1-3]. It is desirable to have a compact size and a small deadspace surrounding the photodetecting surface to achieve high-count rate capability while maintaining high spatial resolution. Very recently, a new compact PS-PMT, Hamamatsu R7600-C12 with an active area of $22\times22\text{mm}^2$, has been developed for scintillation detectors. Eleven stages of metal channel dynodes and $6(x)+6(y)$ crossed plate anodes, are assembled in a 25.7mm square × 20mm high metal can package, whose configuration is shown in Fig.1[4,5]. The PS-PMT has a bialkali photocathode and a thin glass window of 0.8mm in order to minimize the light spread. Since electrons from a dynode are directed to the next dynode entrance, the spatial spread of electron is minimized by an effect of the metal channel dynode structure. This paper describes the results of preliminary studies on the R7600-C12 coupled to different crystals with the aim of applying it to PET.

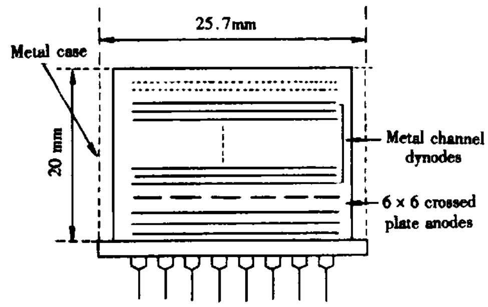

Fig.1 Dimensional outline of R7600-C12.

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2 Experimental Results and Discussion

2.1 Spatial Resolution

Tests of spatial resolution were carried out by coupling a 6×6 LSO (Lu_2SiO_5:Ce) array to the PS-PMT at the center, where the element size of the LSO array is 1.8×1.8mm^2 in cross section and 10mm in depth. All the surface of the crystal elements are mirror-polished, and each element is optically isolated from the adjacent elements with a 0.2mm thick polytetra-fluoro-ethylene (PTFE) film.

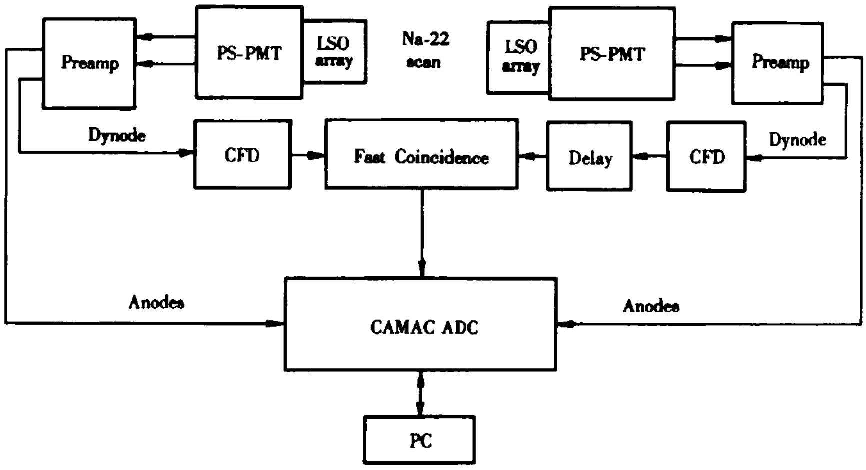

Fig.2 Experimental setup for coincidence response function measurement.

The experimental setup for coincidence response function (CRF) measurement is shown in Fig.2. The cross-plate anodes of the each PS-PMT are connected to resistor chains in each x and y directions, and the output signals (x_+, x_-, y_+, y_-) are amplified with waveform shaping, respectively. The dynode signal from each PMT is fed to the constant fraction discriminator (CFD) and the timing signal is generated. The signals from CFDs are used to determine if a coincidence event had occurred on the Fast Coincidence, where the coincidence window time is set to 15ns. The coincidence signal is used as a gate signal for the analog-to-digital converter (ADC) which converts each output signal to 12 bit digital code and the digital signal are acquired into personal computer (PC) through GPIB interface in list mode. The data were collected by scanning a ^{22}Na point gamma ray source through the central line of detector pairs in 0.25mm steps, covering the effective region of the detector. The measured CRF profiles for the central row of the 6×6 LSO array are shown in Fig.3. The *FWHM* values of the CRFs are approximately equal to 1.4mm for the energy window

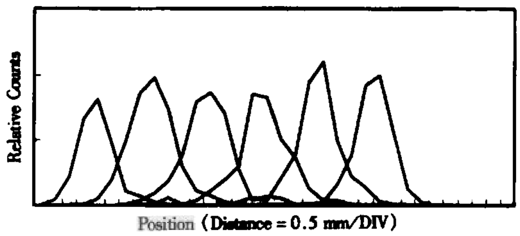

Fig.3 CRF profiles for the LSO detectors measured at γ-ray incident angles of 0°.

350keV - 650keV.

2.2 Spatial Linearity

We investigated the useful area of the PS-PMT for GSO ($Gd_2SiO_5:Ce$) crystals using 22mm × 22mm block composed of 10 × 10 array of 2mm × 2mm × 10mm GSO elements. The 2D positioning histogram (image map) was measured with uniform irradiation of 511 keV γ-rays, which is shown in Fig.4(a). In the positioning histogram all the 100 GSO crystals in the block was clearly separated. The peak profiles of the image along different vertical lines are also shown in Fig.4(b). A good valley to peak ratio is observed.

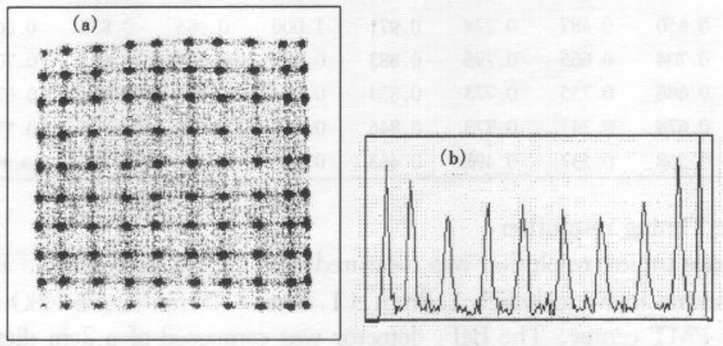

Fig.4 (a) 2D position histogram of the GSO detector measured for uniform irradiation of 511 keV γ-rays (256 × 256-pixel image); (b) Image profile across the 10 elements of the central row.

In order to evaluate spatial positioning linearity, we calculated the crystal separation along the main diagonal in the flood image comparing to the physical crystal separation. Fig.5 shows the results. Near the center, the PS-PMT behaves almost linearly in both x and y directions. However, for the peripheral regions, strong non-linearity is observed. This effect is due to the capability of metal channel dynodes to produce a charge distribution comparable with light distribution.

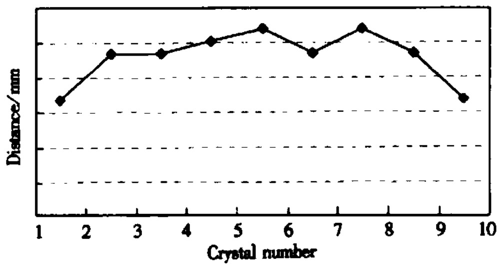

Fig.5 Positioning linearity along the main diagonal in the flood image.

2.3 Gain Uniformity

The gain of the elements, which was defined as channel number of the photopeak maximum of the pulse height distribution, was calculated. The normalized gain variation distribution of the PS-PMT was plotted in the Table 1. Apparently, the gain decreases from the center to the edges and is lowest in the corners. The gain non-uniformity of a PS-PMT across the surface area of entrance window is known to contribute the non-uniform energy resolution of scintillation detectors. The effects of these gain variations are due to electron loss at the edge of each dynode because the electrons gradually spread through the cascade multiplication.

Table 1 Gain variations over the entire effective area of the PS-PMT.

Crystals	1	2	3	4	5	6	7	8	9	10
1	0.517	0.634	0.529	0.502	0.486	0.483	0.529	0.498	0.506	0.556
2	0.524	0.763	0.665	0.654	0.572	0.541	0.584	0.572	0.521	0.564
3	0.685	0.541	0.533	0.702	0.859	0.734	0.514	0.533	0.549	0.541
4	0.584	0.763	0.681	0.726	0.973	0.879	0.912	0.675	0.755	0.617
5	0.607	0.638	0.549	0.823	0.971	0.973	0.88	0.758	0.689	0.658
6	0.662	0.650	0.587	0.724	0.971	1.000	0.965	0.833	0.669	0.665
7	0.767	0.704	0.665	0.795	0.883	0.899	0.781	0.665	0.704	0.716
8	0.778	0.686	0.755	0.773	0.834	0.844	0.681	0.712	0.672	0.651
9	0.809	0.678	0.747	0.773	0.846	0.849	0.635	0.604	0.574	0.672
10	0.525	0.568	0.537	0.498	0.463	0.459	0.494	0.471	0.49	0.483

2.4 Coincidence Timing resolution

The coincidence timing resolution was measured with a BaF_2 detector and a LSO detector for 511keV gamma rays, to which 1.8mm × 1.8mm × 10mm single LSO crystal were coupled to the PS-PMT center. The BaF_2 detector was composed of a 2cm diameter × 2cm crystal and a 29mm diameter PMT, Hamamatsu R1668. Fig.6. shows the timing spectrum and exhibits 0.60ns in *FWHM* and 1.18ns in full width at tenth maximum (*FWTM*).

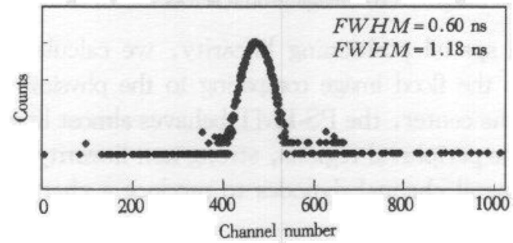

Fig.6 Coincidence timing spectrum obtained between a BaF_2 detector and the PS-PMT, to which 1.8mm×1.8mm×10mm single LSO crystal was coupled to the PS-PMT center.

3 Conclusions

The performance of the new compact PS-PMT was evaluated in terms of applicability to PET system. The new PS-PMT has a thin glass window of 0.8mm in thickness, which reduces the light spread from scintillators. High spatial resolution of about 1.4mm is obtained by using LSO crystals coupled to the PS-PMT. The good spatial linearity, gain uniformity and timing resolution are also obtained by the PS-PMT. The count rate capability, which is important for 3D-PET, can be improved, since the dimension of the PS-PMT is small. These results suggest that the new PS-PMT will be a useful device for the PET detectors.

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5 Hamamatsu Catalog, R7600 - C12

新型位置灵敏光电倍增管的性能测量

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摘要 位置灵敏型光电倍增管(PS-PMT)代表了基于单个管子的原理开发新概念 γ 相机的技术进步. 最近,日本滨松公司出品了一种新型紧凑型的PS-PMT——R7600-C12. 根据正电子放射断层成像系统(PET)的应用特点,我们测试了由该PS-PMT组合成的闪烁晶体阵列探测器的空间分辨率、空间线性度、增益均匀性及时间分辨率 LSO与该PS-PMT的组合空间分辨率达到1.4mm,而且显示出良好的空间线性、增益均匀性及优异的时间分辨特性.

关键词 位置灵敏光电倍增管 探测器 正电子放射断层成像系统

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