A New System for Testing the Static Performance of MCP-PMT

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Abstract. The microchannel-plate photomultiplier tube (MCP-PMT) is the key component in the Daya Bay reactor neutrino experiment II. However, there are few approaches to evaluate its properties. Based on the situation, a testing system and a series of experiments to assess the static performance of MCP-PMT have been developed. The MCP-PMT with 8 inch diameter applied with high voltage is illuminated by appropriate incident light. The cathode and anode current are sampled by capture card to calculate static performance of MCP-PMT. The power spectral density of the anode output current is investigated with FFT. After the experiments are conducted, the system is qualified to test and analyze the static performance of studied MCP-PMT.

Introduction

Microchannel plate(MCP) is a device of arrays of small pores oriented in parallel to each other acting as electron multipliers[1]. The MCP-PMT has several advantages that make it a promising photon detector in high energy physics. High amplification, excellent time resolution, good spatial resolution and compact size result in an increasing interest to the applications of MCP-PMT in practice[2]. As shown in Fig.1 and Fig.2, the MCP-PMT with 8 inch diameter mainly consists of transmission photocathode, reflection photocathode, anode, focusing electrode and two sets of double MCPs. Photoelectrons emitted from round photocathode will be collected by the focusing electrode. Then the electrons are multiplied through MCP1 and MCP2. The amplified current is measured at the anode. The transmission and reflection photocathode are coated on the spherical envelope to form 4π viewing angle photocathode[3].
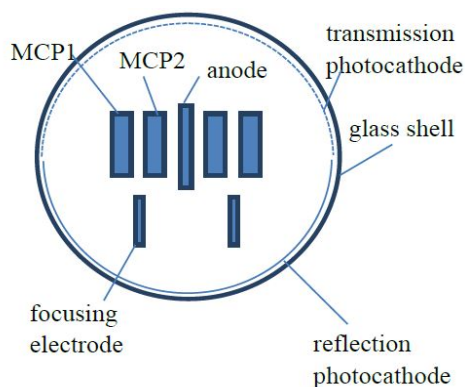

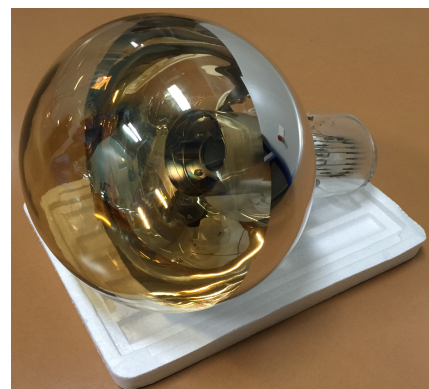Fig. 1: The structure of MCP-PMT

Fig. 2: The MCP-PMT with 8 inch diameter

Parameters

The performance evaluation of MCP-PMT includes the parameters: gain, photocathode sensitivity, anode sensitivity, spectrum sensitivity, quantum efficiency and noise power spectrum.
Gain. The gain (G) of MCP-PMT is defined as the ratio of anode current I_A and cathode current I_K . According to the definition of cathode sensitivity R_K and anode sensitivity R_A, $G = R_A/R_K$ can be deduced.

The gain of single MCP is influenced by the voltage between anode and cathode, material to fabricate the MCP, structure of MCP and the incident electrons. Because it is impractical to measure the secondary electron emission, $G = R_A/R_K$ is actually used to calculate the gain.

Gain of the double MCP-PMT also changes with the distance and channel bias angle between the two MCPs. To achieve the right combination of gain and transit-time-spread(TTS), the distance between two MCPs should be 20-30μm, while the channel bias angle is always between $90°$ and $180°$[4].

Spectrum Sensitivity and Quantum Efficiency(QE). The cathode spectrum sensitivity is defined as the ratio of cathode current I_K and radiant flux E. The cathode current can be calculated with Eq.1, in which $E\lambda/(hc)$ denotes the number of incident photons. From Eq.1, the Eq.2 can be deduced to calculate QE. If the unit of λ is μm, the unit of $R_{K\lambda}$ should be A/W[5].

$$I_K = \frac{E\lambda e\eta(\lambda)}{hc}.$$ (1)

$$\eta(\lambda) = \frac{1.24 I_K}{\lambda E} = \frac{1.24 R_{K\lambda}}{\lambda}.$$ (2)

Noise Power Spectrum. The power spectrum estimation is an important method for spectrum analysis of MCP-PMT's noise performance. The power spectral density(PSD) describes how the power of a signal or time series is distributed over the different frequencies. For a stationary random process, the power spectral density $S_{xx}(\omega)$ and the autocorrelation function $\gamma(\tau) = \langle X(t)X(t+\tau)\rangle$ of the signal should be a Fourier transform pair[6]. In the experiment, $X(t)$ denotes the anode output current.

The power spectral density can actually be computed with the Eq.3. On the other hand, the method that approaches the power spectral density through the autocorrelation function will restrain the thermal noise and provide accurate results.

$$S_{xx}(\omega) = \int_{-\infty}^{\infty} \gamma(\tau)e^{-i\omega\tau}d\tau = \overset{\wedge}{\gamma}(\omega).$$ (3)

System

The schematic diagram of the testing system is presented in Fig.3 and the external view of the system is shown in Fig.4. Tungsten halogen lamp is employed as the light source, which generates the light of 2856K. The intensity of incident light will be reduced by optical filters and apertures. The MCP-PMT detects incident photons placed on the support frame in the opaque chamber that provides a dark environment. The box is fabricated with soft iron, which improves magnetic shielding efficiency and avoid the influence of outer magnetic field. The anode and cathode current will be measured by corresponding galvanometer. The IPC samples anode and cathode current to calculate the parameters which are processed in software module.
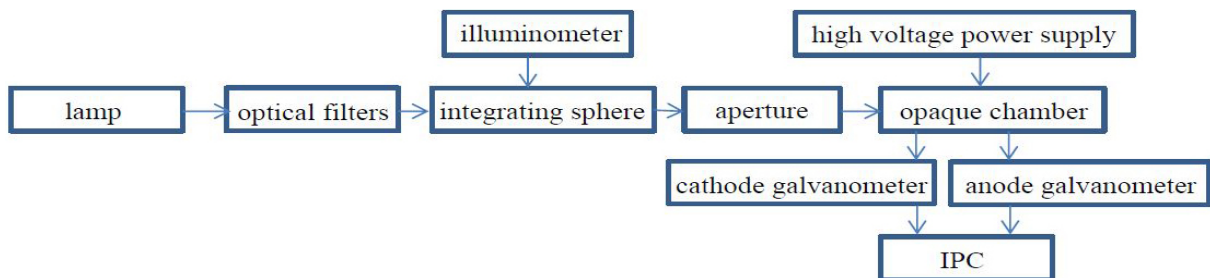
Fig. 3: The schematic diagram of the testing system

Analysis of Static Performance

Power Spectrum. One set of the double MCPs is tested for the static performance evaluation. We change the applied voltages of two MCPs and sample the anode output current to analyze its noise power spectrum. The voltage between cathode and focusing electrode is 100V, which is the same with the voltage between anode and MCP2. The sampling frequency of IPC reaches 10,000Hz, and 100,000 data are sampled under every voltage. The power spectral density of anode current with incident light at 410nm wavelength is presented in Fig.5, which has eliminated the power line interference.

In Fig.5, the power spectrum falls off steadily under 30Hz, which exhibits the property of 1/f noise, whereas the higher frequencies are overshadowed by low-pass filter in anode galvanometer. If the anode output current is kept low, thermal noise that is presented as the jitter at high frequencies on the power spectrum will be the predominant effect[7]. With the increasing of MCP's voltage, the noise power spectral density is boosted.

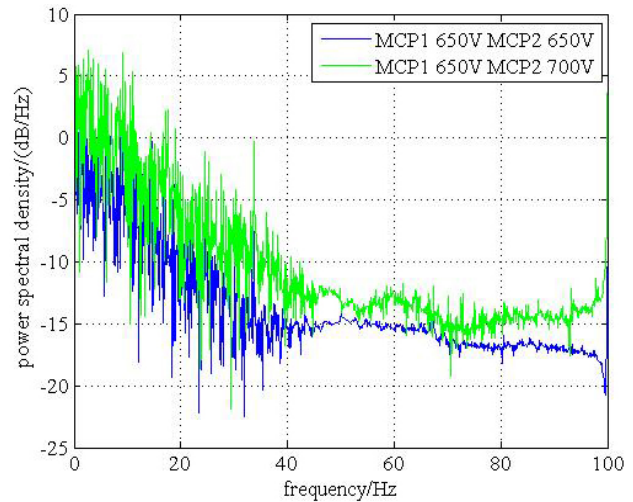Fig. 4: The external view of the system

Fig. 5: The power spectral density of 410nm incident light

Cathode Parameters. The cathode parameters are listed separately in Table 1 and Table 2. When the cathode parameters are tested, no voltages are applied to the studied MCPs. The photoelectrons collected by the focusing electrode are directly measured by the cathode galvanometer. Through the system, we can get the cathode parameters in full spectrum and 410nm wavelength.

Table 1: The cathode parameters in full spectrum

incident light	cathode current(nA)	cathode sensitivity($\mu A/lm$)	luminous flux(μlm)
attenuated of 10^2	0.847	41.26	20.5483

Table 2: The cathode parameters at 410nm wavelength

incident light	cathode current(nA)	cathode spectrum sensitivity(mA/W)	quantum efficiency(%)	radiant flux(nW)
410nm	3.400	80.12	24.21	42.52

Anode Parameters. The anode parameters are listed separately in Table 3 and Table 4. When the parameters in full spectrum are measured, the intensity of incident light is reduced 10^4 level by employing appropriate neutral optical attenuator. When the parameters at 410nm wavelength are measured, the neutral optical attenuator of 10^4 and 410nm optical filter are both applied to obtain monochromatic light incidence .

As shown in Table 3 and Table 4, the anode parameters rise with the increasing of MCPs' voltages. The testing system measures the anode current precisely and computes other corresponding parameters which are compatible with the typical properties of MCP-PMT.

Table 3: The anode parameters in full spectrum

MCP1(V)	MCP2(V)	dark current(μA)	anode current(μA)	anode sensitivity(A/lm)	gain
750	750	1.521	16.634	1.280	3.101×10^4
750	700	1.650	14.623	1.099	2.663×10^4
650	700	0.973	11.235	0.864	2.095×10^4
650	650	0.714	9.697	0.746	1.808×10^4

Table 4: The anode parameters at 410nm wavelength

MCP1(V)	MCP2(V)	anode spectrum sensitivity(A/W)	anode current(μA)
750	750	3.714×10^5	1.579
750	700	1.244×10^5	0.529
650	700	7.949×10^4	0.338
650	650	5.715×10^4	0.243

Conclusions

According to the testing results, the system provides a useful method to approach the static performance of MCP-PMT, such as gain, anode current, cathode current, anode sensitivity, cathode sensitivity and quantum efficiency. These properties can be measured precisely in different MCPs' voltages, which reflects the reliability of the system. In addition, we can distinguish the 1/f noise in the power spectrum of anode current and confirm the higher frequencies are restrained by the low-pass filter in anode galvanometer. In the present work, the system is qualified to test the static performance of MCP-PMT.

Acknowledgement

References

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