COUNT RATE PERFORMANCE OF A MICROCHANNEL PLATE PHOTOMULTIPLIER*

EGG-M--02181

E. B. Nieschmidt, R. S. Lawrence, C. D. Gentillon

CONF. 811012--49

DE82 007335

EG&G Idaho, Inc.
P. O. Box 1625
Idaho Falls, ID 83415

and

S. H. Vegors, Jr.

Idaho State University
Pocatello, ID 83209

MASTER

ABSTRACT

The count rate dependent gain change of a microchannel plate photomultiplier has been measured. Gain changes of 60% have been observed for count rates in excess of $2 \times 10^5 \text{ s}^{-1}$. The microchannel plate photomultiplier was used as a multiplying element of a scintillation detector system using NaI(Tl) as the scintillator. Data are compared to a simplified model of this form of photomultiplier.

INTRODUCTION

Microchannel plate photomultipliers (MCP) are attractive for certain applications. These attractions are their speed for pulse-shape discrimination, and low susceptibility to small and changing magnetic fields. Both of these attributes are because the entire electron motion is very small.

The materials from which the MCP is fabricated are high resistivity^{1, 2, 3} glass and semiconductors. Because of this high resistivity, one would expect significant gain changes at high counting rates when such a device is incorporated into a nuclear spectrometry system.

The objectives of this undertaking were to measure the rate dependent gain of a MCP and to develop a simple calculational model to predict these changes. The MCP was operated in the pulse saturation mode providing an output proportional to the number of photons at the input to the photocathode. The calculational model uses only parameters of the MCP which are available from the manufacturer.

EXPERIMENTAL

A block diagram of the experimental setup is shown in Figure 1. The characteristics of the scintillation detector and MCP are given in Table 1. The preamplifier is a modification of one described by Spieler⁴ and is used in the current-sensitive mode. The wide band amplifier and base-line restorer were constructed at this laboratory and have been described by Lawrence and Johnson⁵. The pulse height analyzer (PHA), high-voltage power supply, and printer were commercial items.

Two sources of radiation were used in these experiments. They were ²²Na and ¹³⁷Cs of approximately 100 μCi and 300 μCi respectively. Interaction rates in the scintillator were controlled by changing the source to detector distances. A 0.63 cm thick lucite absorber was used between the source and detector to eliminate β -ray interactions in the scintillator.

*Work supported by the U. S. Department of Energy under DOE Contract No. DE-AC07-761D1570.

DISCLAIMER

This book was prepared as an account of work sponsored by an agency of the United States Government. Neither the United States Government nor any agency thereof, nor any of their employees, makes any warranty, express or implied, or assumes any legal liability or responsibility for the accuracy, completeness, or usefulness of any information, apparatus, product, or process disclosed, or represents that its use would not infringe privately owned rights. Reference herein to any specific commercial product, process, or service by trade name, trademark, manufacturer, or otherwise, does not necessarily constitute or imply its endorsement, recommendation, or favoring by the United States Government or any agency thereof. The views and opinions of authors expressed herein do not necessarily state or reflect those of the United States Government or any agency thereof.

Figure 1. Experimental System Block Diagram

TABLE 1

PHOTOMULTIPLIER AND SCINTILLATOR CHARACTERISTICS

Scintillator

Type: NaI(Tl) Crystal
Dimensions: 3.8 cm diameter X 2.54 cm height

Microchannel Plate Photomultiplier

Type: ITT Model F4129
Anode: Single
Cathode: Bialkali
18 mm diameter
Plate: Z plate configuration
 1.3×10^6 channels
Gain: $10^6 \text{ e}^-/\text{e}^-$ at 2400 volts

Care was taken to insure that zero energy corresponded to near channel zero in the PHA. The value of the energy intercept was monitored throughout the experiment. Any large deviation of the intercept from zero would imply improper operation of the base-line restorer and questionable data.

Stability of electronic gain was measured by injecting a pulse generated by a precision pulser at the input of the preamplifier. No drift of the electronic system was detected, nor was any gain change of the electronics detected with changing counting rate.

Because of the mismatch of scintillator diameter and photocathode diameter, data were obtained with and without a tapered lucite light pipe. No substantial differences in the spectra were observed.

During the course of the experiments, it was observed that considerable time was required for the gain to achieve its equilibrium value after a change in counting rate. Observations were made of this time de-

DISCLAIMER

This report was prepared as an account of work sponsored by an agency of the United States Government. Neither the United States Government nor any agency Thereof, nor any of their employees, makes any warranty, express or implied, or assumes any legal liability or responsibility for the accuracy, completeness, or usefulness of any information, apparatus, product, or process disclosed, or represents that its use would not infringe privately owned rights. Reference herein to any specific commercial product, process, or service by trade name, trademark, manufacturer, or otherwise does not necessarily constitute or imply its endorsement, recommendation, or favoring by the United States Government or any agency thereof. The views and opinions of authors expressed herein do not necessarily state or reflect those of the United States Government or any agency thereof.

DISCLAIMER

Portions of this document may be illegible in electronic image products. Images are produced from the best available original document.

pendent gain change. However, this problem was not pursued further. Because of this effect, spectra were obtained only after sufficient time had elapsed for equilibrium to be established.

DATA TREATMENT

The use of the number of counts accumulated in a spectrum to determine scintillator interaction rates at high counting rates is unreliable. At high rates, the probability of photoelectrons striking low-gain channels is high. This can cause full energy interactions in the scintillator to appear well below the full energy peak in the PHA spectrum. The large number of resultant small pulse heights requires a high threshold discriminator setting. Because of the high discriminator setting, many interactions are unrecorded, and interaction rates cannot be reliably determined.

To obtain accurate interaction rates, they were controlled by changing the source to detector distances. For the sources used in these experiments, the dead-time corrections at a distance of 100 cm were negligible. Interaction rates at 100 cm were defined as the count rate at 100 cm. Interaction rates at other distances were obtained from

$$r_X = r_{100} (100/X)^2 C_X$$

where:

r_X = calculated interaction rate at distance X cm.

r_{100} = measured count rate at 100 cm.

C_X = ratio of detector intrinsic efficiencies at X cm and 100 cm.

Gaussian functions were fit to the full energy peaks in the pulse-height data. The fits yielded mean channel numbers for the full energy peaks as well as peak widths. To eliminate any effects of Compton distributions the fit limit on the low energy side of the full energy peak was the channel corresponding to 80% of the peak channel value. The high energy fit limit was chosen as that channel containing 10% of the counts of the peak channel. The peak positions of the 511 keV annihilation radiation and the 1274 keV gamma-ray from a ^{22}Na source were used to determine gains expressed as keV/channel.

The results of gain versus count rate measurements are shown in Figure 2. The rates indicated in Figure 2 are uncorrected for discriminator setting.

Figure 2. Fractional Gain Change vs. Count Rate

EMPIRICAL THEORY

The MCPP construction and operation have been described¹. A model describing the gain of a MCPP has been presented by Eberhardt⁶.

The MCPP consists of a large number ($\sim 10^6$) of small diameter ($\sim 10\mu\text{m}$) glass tubes arranged in a hexagonal close pack. The interior of these is coated with a semiconducting material and a potential difference is applied across the ends. When an energetic electron collides with the sides of a channel, secondary electrons are ejected. These secondary electrons are accelerated down the channel until they impact a wall creating further multiplication. It appears that there is a preferred distance between wall collisions or the channel is "Dynodized"⁷.

The material comprising the walls of the channels has very high resistivity. Consequently, immediately after a multiplication, the surface electron charge is partially depleted. A definite time is required to reestablish this surface charge distribution. In addition to electron depletion, the magnitude of the potential gradient between adjacent "dynodes" is increased. As the local potential in the vicinity of a "dynode" is raised the effective work function of the surface material is increased.

The gain per stage of such a device is dependent upon all three of these effects. These effects all change in some complicated manner.

If one assumes that the gain of a MCPP can be represented by the average gain of a typical channel the following arguments will provide a model for calculating this average gain.

The distribution of time intervals between uses of a channel from a random source is

$$I(t)dt = Re^{-Rt}dt$$

where R is the average rate of using the channel in question. If one further assumes that after a detection the gain is decreased a fraction k, and that the gain recovers to its initial value with a characteristic time τ , the charging time through the high resistivity material, one may write

$$G(t) = G_0 (1 - ke^{-t/\tau})^\beta \quad (1)$$

In Equation (1), G_0 is the initial gain and β is a constant described below. With the above time interval distribution function the mean gain is

$$\bar{G} = \frac{\int_0^\infty I(t) G(t) dt}{\int_0^\infty I(t) dt}$$

and

$$\frac{\Delta G}{G_0} + 1 = \frac{\bar{G} - G_0}{G_0} + 1 = \frac{\int_0^\infty e^{-Rt} (1 - ke^{-t/\tau})^\beta dt}{\int_0^\infty e^{-Rt} dt} \quad (2)$$

If one chooses $\beta=1$

$$\frac{G}{G_0} + 1 = 1 - \frac{kR}{R + \frac{1}{\tau}}$$

The results of this calculation as a function of R , with $\tau = 0.02$ s, $k = 0.2, 0.5$, and 1.0 , are shown in Figure 3.

The inter-dynode gain of a MCPD while operating in the linear region is

$$G \propto \left(\frac{V}{V_C} \right)^{0.7}$$

$V_C = \text{constant}$

$V = \text{inter-dynode potential}$

Since the infinite limits cannot be handled by numerical methods the limits of integration have been reduced see the appendix. The resulting gain changes with rate are shown in Figure 3.

These calculational results are to be compared with the experimental results, see Figure 3. To make this comparison, the rates of using a channel have been calculated from the observed resolution in the following manner.

The resolution of a full energy gamma-ray peak may be calculated from

$$\text{Resolution} = 2.35 \frac{\sqrt{N}}{N}$$

where N is the number of electrons striking the channels of the MCPD. The measured resolution of the 661 KeV gamma-ray from ^{137}Cs is 19.2% at low counting rates, yielding

$$N = 149 \frac{e^-}{661 \text{ keV}}$$

here 661 keV is the amount of energy deposited in the NaI(Tl) crystal.

To obtain R , the average amount of energy deposited

per gamma ray for the entire spectrum must be known.

For ^{22}Na at low counting rates this is 280 keV. Hence, on the average, 63 electrons will strike the channels of the MCPD per ^{22}Na gamma ray. Each incident electron effectively saturates six channels⁷, and since there are 1.3×10^6 channels in the MCPD, R is

$$R = \frac{63 \times 6}{1.3 \times 10^6} \times (\text{interaction rate})$$

or

$$R = 2.9 \times 10^{-4} r$$

where r is the interaction rate. The results for rate (R) calculated in this manner agree well with those calculated by the method presented in the next section.

Use of $g = 1.0$ and $k = 0.5$ in the agreement with the experimental results, see Figure 3.

USE OF THE MODEL

The parameters of the model are:

1. The characteristic recharge time (τ) of a channel or group of channels. This information is available from the manufacturer.
2. The number of channels (M) the plate contains, again available from the manufacturer.
3. The quantum efficiency of the photocathode (η) at the emission wavelength of the scintillator. This data is available from the manufacturer and is standardized for the various photocathode responses.
4. The effective electron open area ratio Y .
5. The ratio of the areas of the scintillator (A_s) and photocathode (A_p).

Figure 3. Rate Dependent Gain Change From Empirical Model

6. The conversion efficiency of the scintillator (η); that is, the yield of photons per unit of charged particle energy deposited in the detector.

The rate of using a given channel by the detection of interactions which deposit an average energy E , at a rate r is

$$R = \frac{A_p}{A_s} \cdot \frac{\eta E q Y}{M} r \quad (s^{-1}).$$

This study shows that this rate R may be used to estimate the fractional gain change from the relationship

$$\frac{\Delta G}{G} + 1 = 1 - \frac{KR}{R + \frac{1}{\tau}}$$

where k is the fraction that the gain of a channel changes because of a use. This yields the average fractional gain change of a channel. Since all channels are equivalent it yields the fractional gain change of the device.

CONCLUSIONS

When used as a multiplying element of a nuclear scintillation pulse spectrometry system the gain of a MCPD changes significantly with counting rate. This rate change is particularly aggravated when a high conversion efficiency scintillator such as NaI(Tl) is used.

An empirical model has been developed for the calculation of gain changes as a function of channel use rate. The parameters of the model use information which is available from the manufacturer of the MCPD. The model works well for channel use rates $R < 500 s^{-1}$.

APPENDIX

DETERMINATION OF UPPER LIMITS FOR NUMERICAL INTEGRATION

This appendix deals with the evaluation of the average gain,

$$\bar{G} = \int_0^{\infty} G(t) I(t) dt$$

where

$I(t) = Re^{-Rt}$, the probability density of time to a channel being disabled by an entering electron. The form of $G(t)$ may require numerical integration and one thus estimates average gain with respect to a truncated time distribution:

$$\begin{aligned} G^* &= \frac{\int_0^u G(t) I(t) dt}{\int_0^u I(t) dt} \\ &= \frac{\int_0^u G(t) I(t) dt}{1 - e^{-Ru}} \end{aligned}$$

The selection of an appropriate upper bound u controlling the truncation error $\bar{G} - G^*$ is discussed below.

Note that

$$\bar{G} = \int_0^u G(t) I(t) dt + \int_u^{\infty} G(t) I(t) dt$$

$$= (1 - e^{-Ru}) G^* + \int_u^{\infty} G(t) I(t) dt.$$

Since $0 \leq G(t) \leq 1$, the following also holds

$$0 \leq \int_u^{\infty} G(t) I(t) dt \leq \int_u^{\infty} I(t) dt = e^{-Ru}.$$

Therefore,

$$[(1 - e^{-Ru}) G^* + 0] - G^* \leq \bar{G} - G^* \leq [(1 - e^{-Ru}) G^* + e^{-Ru}] - G^*.$$

Simplifying this expression produces

$$-e^{-Ru} \cdot G^* \leq \bar{G} - G^* \leq e^{-Ru} \cdot (1 - G^*).$$

With $G(t)$ in $[0, 1]$, G^* is in $[0, 1]$ and the maximum of G^* and $1 - G^*$ is less than 1. Hence, e^{-Ru} is an upper bound on the magnitude of the error.

To guarantee that $|\bar{G} - G^*|$ is less than a specified limit, A , one chooses

$$u \geq -\frac{\log A}{R}$$

In this study, 0.001 was used for A to limit the truncation error to less than 1%.

ACKNOWLEDGEMENTS

The authors wish to express their thanks to L. O. Johnson for his many helpful technical discussions and to Eunice Rahl for her expertise in producing the manuscript.

REFERENCES

1. S. Dhawn and R. Majka, IEEE Trans. Nucl. Sci., NS-24, 270, (1977).
2. S. Dhawn, IEEE Trans. Nucl. Sci., NS-28, 672 (1981).
3. D. H. Ceckowski et al, IEEE Trans. Nucl. Sci., NS-28, 677 (1981).
4. H. Spieler, IEEE Trans. Nucl. Sci., NS-17, 302, 1970.
5. R. S. Lawrence and L. O. Johnson, An Electronic System for Transuranic Waste Assays Using a Photon Interrogation Technique, EGG-PHYS-5076, (Dec. 1979).
6. E. H. Eberhardt, Applied Optics, 18, 1418, (1979).
7. E. H. Eberhardt, Parameters Pertaining to Micro-channel Plates and Microchannel Plate Devices, ITT Technical Note 127, (August 1980).