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Determination of Geiger Mueller Counter Dead Time Using Statistical Parameter of Time Interval Distribution

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1. Introduction

Dead time in the Geiger Mueller (GM) counter not only causes count loss but also influences the statistical parameters of the measured (observed) count and its time interval distribution. Due to the count loss induced by dead time, the Poisson distribution of true count is distorted and consequently the statistical parameters are changed. Many studies have been done to analyze the detector dead time, including GM counter, based on the changed of the statistical parameters [1-5]. One of the methods proposed from these studies is variance-to-mean ratio (VTMR) method [2]. By this method, the dead time can be inferred using the degree of the distortion of Poisson statistic of measured count compared to the true count. The variance of true Poisson count is equal to the expected value, $\sigma^2(nt) = nt,$ therefore the VTMR = 1, but because of the count loss in the measured counts, the variance of measured count is not equal to its expected measured counts.

Analytical formulas of variance to mean ratio of some dead time models have been derived in previous studies [1,3]. Two models that were studied in this paper are nonparalyzable (NP) and paralyzable (P) models. In the nonparalyzable model, the events that occur during dead time portion of the detector are not counted and the dead time is not extended, while in the paralyzable model, events that occur in dead time portion are not counted and also cause the dead time reset and extended. Other model is hybrid model that can be in NP-P model or P-NP model. These models are illustrated in Fig. 1 [5].

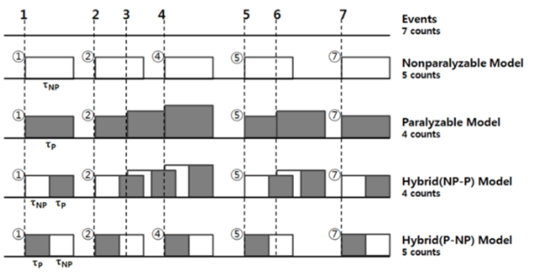

Fig. 1. Illustration of counts registered by NP, P and hybrid dead time models.

The variance to mean ratio of nonparalyzable model, is given as:

$$VTMR = \frac{\sigma^2(mt)}{mt} = 1 - 2\tau_{NP}m + \tau_{NP}^2 m^2 \quad (1)$$

where $\sigma^2(mt)$ is variance of measured count, m is measured count rate, t is measurement time and τ_{NP} is dead time of nonparalyzable model.

This analytical formula is simplified from the equation given in the reference [1], and has been experimentally proved by Hashimoto, et al. [2] for GM counter and proportional neutron counter.

Furthermore, the VTMR for the paralyzable dead time model derived by Kosten [3,4], is given as:

$$VTMR = \frac{\sigma^2(mt)}{mt} = 1 - 2\tau_P m + \frac{\tau_P^2\, m}{t} \quad (2)$$

where τ_P is dead time of paralyzable model.

In this paper, the Monte Carlo simulation was used to generate the statistical parameters of counts and its time interval distribution (TID). The Monte Carlo simulation was chosen because it provide more efficient and easier method compared to the experimental methods, such as two-source method and decaying source method.

The main objective of this study is determining the dead time of the paralyzable and nonparalyzable models by using the statistical parameters of the counts and their time interval distribution (TID) that are resulted in Monte Carlo simulation. The degree of statistical parameter distortion of count and its TID from the Poisson and exponential time interval distribution is used to infer the dead time. The particular statistical parameters used are VTMR of counts and coefficient of variation of time interval distribution. In the real measurement, implementation of VTMR of counts method or coefficient of variation of TID depend on the availability of measurement system, where for TID, time interval analyzer is needed.

2. Materials and Methods

The Monte Carlo GM counter simulator, GMSIM, using FORTRAN software, that has been developed previously by Lee and Gardner [4] was updated in this study. This method requires detector dead times, true count rates and measurement time as input data to produce observed (measured) total counts, count rates, and its statistical parameters; time interval distribution of measured counts and its statistical parameters, including time interval average and variance. In this simulator, pseudorandom numbers are generated and a time interval, t, between two radiation events are randomly sampled from the well-known interval distribution,

$$f(t)dt = n \cdot exp(-nt)dt \qquad (3)$$

Four cases of two models were simulated with total dead time of 300 µs and 150 µs. The four cases are two nonparalyzable models (τ_{NP} = 300 µs and τ_{NP} = 150 µs) and two paralyzable models (τ_P = 300 µs and τ_P = 150 µs). Each model was run in 18 count rate variations, from 20 to 10000 counts per second (cps).

The simulation output were used to obtain VTMRs of different count rates. The VTMRs were then fitted with their measured count rates to compare the GMSIM results to the values obtained from the equations (1) and (2), in order to validate the GMSIM. In the next step, the coefficient of variation of the time interval distribution were plotted with the measured count rates to determine the dead time parameter of nonparalyzable and paralyzable models.

3. Results and Discussion

Hashimoto, et al. [2] have studied the variance to mean ratio experimentally to determine the dead time of the GM Counter and neutron proportional counter. This experiment successfully demonstrated the validity of the Müller first- and second-order VTMR expressions to be used in determining the dead time of the nonparalyzable model. Using the GMSIM, the variance to mean ratio analysis for nonparalyzable and paralyzable models were performed in this study. The results are shown in the Table I for 150 µs dead time for both nonparalyzable and paralyzable, Fig. 1 and Fig. 2 for 300 µs dead time of nonparalyzable and paralyzable models.

Table I: Comparison of VTMRs resulted in GMSIM to Mueller formula (eq. (1)) for nonparalyzable model; and to Kosten formula (eq. (2)) for paralyzable model.

Count rate (cps)			Variance to mean ratio			
Input/ true	Measured		$\tau_{NP} = 150\ \mu s$		$\tau_P = 150\ \mu s$	
	NP	P	GMSIM	Eq. (1)	GMSIM	Eq. (2)
20	19.984	19.984	0.998	0.994	0.998	0.998
40	39.751	39.750	0.993	0.988	0.993	0.993
60	59.425	59.423	0.987	0.982	0.988	0.988
80	79.116	79.112	0.980	0.976	0.980	0.980
100	98.376	98.364	0.983	0.971	0.983	0.983
200	199.79	193.87	0.980	0.941	0.926	0.926
300	286.97	286.69	0.948	0.916	0.947	0.947
400	377.16	376.50	0.882	0.890	0.879	0.879
500	465.01	463.76	0.854	0.865	0.850	0.850
600	550.23	548.15	0.821	0.842	0.816	0.816
700	634.08	630.82	0.810	0.819	0.803	0.803
800	714.43	709.65	0.790	0.797	0.779	0.779
900	792.61	785.99	0.775	0.776	0.764	0.764
1000	869.24	860.34	0.750	0.756	0.736	0.736
2000	1538.6	1481.8	0.577	0.592	0.545	0.545
4000	2500.3	2195.6	0.384	0.391	0.335	0.335
8000	3636.7	2409.8	0.206	0.207	0.272	0.272
10000	3999.8	2231.2	0.159	0.160	0.333	0.333

The GMSIM results show that the variance to mean ratio obtained by equation (1) for nonparalyzable model and equation (2) for paralyzable model are very close to the GMSIM results. Therefore the GMSIM results can be used further to determine the dead time.

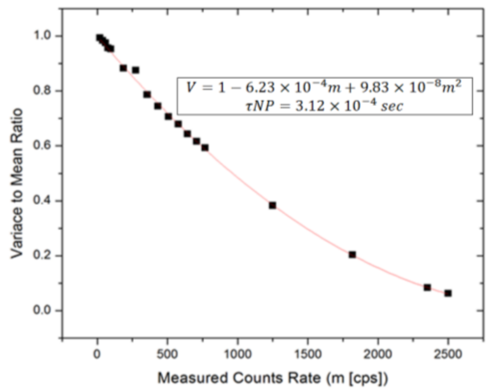

Fig. 1. GMSIM variance to mean ratio for nonparalyzable model (τ_{NP} = 300 µs).

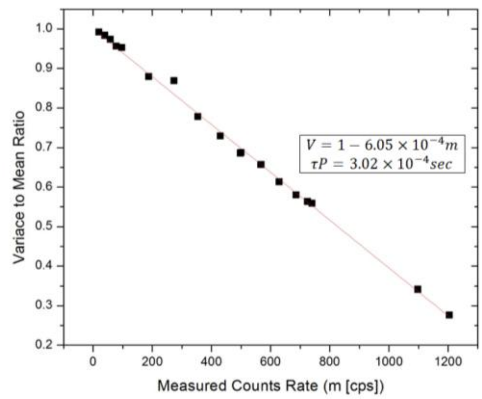

Fig. 2. GMSIM variance to mean ratio for paralyzable model (τ_P = 300 µs).

By fitting the results of the GMSIM, dead time can be determined which are: 154±4 µs, 312±6 µs for nonparalyzable model using dead time input parameter of 150 µs and 300 µs, while for paralyzable model, the GMSIM results are 151±1 µs, and 302±2 µs, using same dead time input parameter as nonparalyzable model.

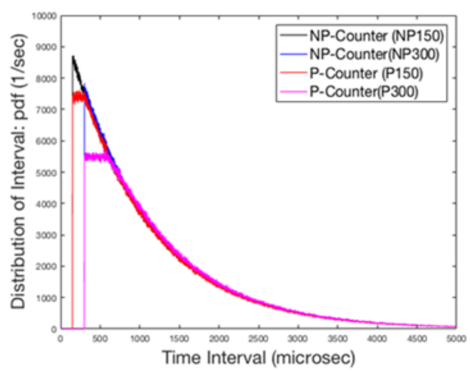

Fig. 3. Distorted time interval distribution of nonparalyzable and paralyzable models with τ = 150 and τ = 300 µs).

Furthermore, using similar approach to VTMR, the statistical parameters of time interval distribution were used to determine the dead time of the nonparalyzable and paralyzable models. Time interval distribution method have been applied in previous studies [5,6]. The result of previous study [5] showed that the statistical parameters of time interval distribution can be used to distinguish different dead time models, as shown in Fig. 3. This figure shows the distorted exponential time interval distribution for nonparalyzable and paralyzable models.

Table II: Coefficient of variation of time interval distribution for the nonparalyzable and paralyzable models.

Count rate (cps)			Coefficient of variation			
Input/ true	Measured		Nonparalyzable		Paralyzable	
	NP	P	τ=150 μs	τ=300 μs	τ=150 μs	τ=300 μs
20	19.984	19.984	1.000	0.996	1.000	0.996
40	39.751	39.750	0.995	0.989	0.995	0.989
60	59.425	59.423	0.989	0.981	0.989	0.980
80	79.116	79.112	0.988	0.977	0.988	0.977
100	98.376	98.364	0.983	0.969	0.983	0.969
200	199.79	193.87	0.971	0.943	0.970	0.942
300	286.97	286.69	0.956	0.917	0.955	0.913
400	377.16	376.50	0.944	0.893	0.942	0.887
500	465.01	463.76	0.931	0.870	0.928	0.861
600	550.23	548.15	0.918	0.848	0.914	0.837
700	634.08	630.82	0.905	0.826	0.900	0.812
800	714.43	709.65	0.892	0.806	0.887	0.788
900	792.61	785.99	0.881	0.788	0.874	0.767
1000	869.24	860.34	0.870	0.770	0.861	0.746
2000	1538.6	1481.8	0.769	0.625	0.745	0.584
4000	2500.3	2195.6	0.625	0.455	0.584	0.527
8000	3636.7	2409.8	0.455	0.294	0.526	0.751
10000	3999.8	2231.2	0.400	0.250	0.575	0.837

In this study, the statistical parameter of the distorted TID resulted in the GMSIM used to determine dead time is coefficient of variation. The coefficient of variation is the ratio of standard deviation to the expected value (mean), which is equal to 1 for exponential distribution. However, because the TID of measured count is distorted, then the coefficient of variation will be less than 1.

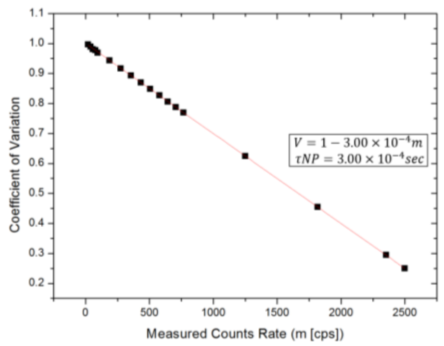

Fig. 4. GMSIM coefficient of variation of the time interval distribution for nonparalyzable model ($\tau_{NP} = 300$ μs).

The coefficient of variations for different count rates resulted in the GMSIM for nonparalyzable and paralyzable models with 150 and 300 μs dead times are given in the Table II. The coefficient of variations are then fitted with their measured count rates as shown in Fig. 4 for nonparalyzable model and Fig. 5 for paralyzable model.

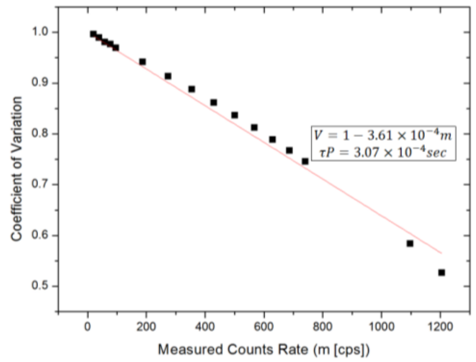

Fig. 5. GMSIM coefficient of variation of the time interval distribution for paralyzable model ($\tau_P = 300$ μs).

Based on these data fitting, equations for determining the dead time of nonparalyzable and paralyzable model are derived as follows:

$$\frac{\sigma(\Delta t)}{\Delta t} = 1 - \tau_{NP}.m \qquad (4), \text{and}$$

$$\frac{\sigma(\Delta t)}{\Delta t} = 1 + \frac{1}{1.7}(\tau_P^2 - 2\tau_P)m \qquad (5).$$

The study results show that the nonparalyzable and paralyzable dead time determined by the variance to mean ratio of counts and the coefficient of variance of time interval distribution are very close, therefore both method can be used depend on the availability of the measurement system.

4. Conclusion

Coefficient of variation of the distorted time interval distribution resulted in GMSIM has been implemented to determine the dead time of the nonparalyzable and paralyzable model. The resulted nonparalyzable and paralyzable dead time by the variance to mean ratio and the coefficient of variation of time interval distribution are very close. Therefore both method can be used depend on the availability of the measurement system needed. However further experimental study especially for coefficient of variation of TID is needed to validate the method.

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