Determine on the dead time of a GM counter

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1. Introduction

A Geiger-Müller (GM) counter is one of the oldest but still most widely used detectors. Its utility for high counting rates is, however, limited due to its long dead time (DT) of a few hundred μs to several ms. Studying the DT characteristics of GM counters can extend the range of useful counting rates and therefore enhance the applications of GM counters.

2. DT models

The study by Müller on the generalized DT model considered a DT as a non-extending (NE) or extending (E) type occurring with a certain probability in a counting circuit [1]. Here, the circuit DT was schematically described as a parallel combination of E and NE DTs as shown in Fig. 1(a). In Fig. 1, τ_E and τ_{NE} are the magnitudes of E and NE DT, respectively. When both DTs were of the same magnitude τ, the overall influence of DTs was given as

$$R = \frac{\theta n}{\exp(\theta n \tau) + \theta - 1} \quad (1)$$

where R was the measured counting rate by the circuit and n was the true counting rate. It is clear that if θ becomes 0 or 1, the model is reduced to a NE or E DT model, respectively.

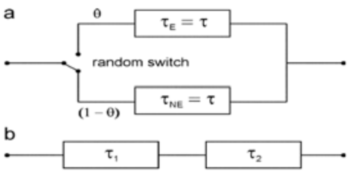

Fig. 1 Schematic block diagram of the DT circuit.

The series DT models [2-5] consider the statistical effect of cascaded DT combinations in counting circuits as shown in Fig. 1(b), where τ_1 and τ_2 are the DTs of the first and second circuits, respectively. Since a smaller DT of the following circuit ($\tau_2 < \tau_1$) has no effect on the overall counting, only a larger DT than the preceding one ($\tau_2 > \tau_1$) is meaningful and considered in the series model. Accordingly, when both DTs are activated by a registered count, during the period of the second DT, the part that overlaps with the first DT has no incoming pulses due to the masking effect of the first DT. Hence the difference $\tau_2 - \tau_1$ is relevant for discussions on the second DT effect. In this study, the magnitude of the second dead time, τ_2, was decomposed into a magnitude of τ_1 and the residual part τ_E (or τ_{NE}) according to its type. Decomposition was only performed for simplicity in describing the relevant rate equations, but had no effect on the nature of the second DT. For each case of the series DT models, the relation between the measured counting rate R and the true counting rate n is given as

(i) Series (NE-E) model ($\tau_1 = \tau_{NE}$, $\tau_2 = \tau_1+\tau_E$);

$$R = \frac{n\exp(-n\tau_E)}{1 + n\tau_{NE}} \quad (2)$$

(ii) Series (E-NE) model ($\tau_1 = \tau_E$, $\tau_2 = \tau_1+\tau_{NE}$);

$$R = \frac{n\exp(-n\tau_E)}{1 + n\tau_{NE}\exp(-n\tau_E)} \quad (3)$$

The present study suggests an empirical two-parameter rate equation for GM DT effects to explain the counting rate in a wide range. This is given as:

$$R = \frac{n\exp(-n\tau_E)}{1 + n[(\tau_{NE} + \tau_E) - \tau_{NE}\exp(-n\tau_E)]} \quad (4)$$

Where τ_E, τ_{NE} are DTs of the same nature in the series model and are left as parameters to fit the measured counting rates.

3. Experimental set

An experimental set was prepared as shown in Fig. 2. The discrimination level at the MCS was set to -50 mV. The operation bias was 1300 V as determined by a plateau measurement. The slope of the plateau was about 4.1%/100 V, indicating the normal condition of the used GM probe. The observed background rates had a mean of 0.315 cps and a standard deviation of 0.053 cps.

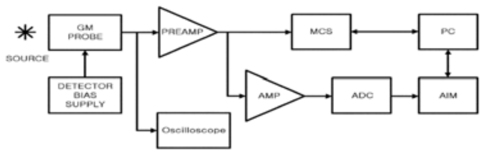

Fig. 2 Block diagram of the DT measurement system for a GM counter.

A ^{56}Mn source was used as the decaying source. It has a half life of 2.579 h and is prepared by a neutron irradiation of ^{55}Mn (natural abundance: 100%). The amount and irradiation time of ^{55}Mn was chosen to achieve an initial true counting rate of 50 kcps after considering the cooling time for a delivery to the counting room. The mass of ^{55}Mn was 42 mg with a thickness of 1.5 mm. It was irradiated for an hour in a thermal neutron flux of 9×10^9 n/cm^{2}s.

4. Results and Discussion

Counting measurements of the ^{56}Mn source were taken for 3200 min. Dwell time in the MCS was set to 1 min. The variations in the counting rate are shown in Fig. 3 as a function of the decay time. The maximum observed counting rate of the GM detector was about 600 cps due to the DT effect. To determine the true counting rate *n(t)*, the following relation was used to fit the rate data:

$$n(t) = n_0 \exp(-\lambda t) + n_B \quad (5)$$

where λ is the decay constant of ^{56}Mn, 4.480×10^{-3} min^{-1}, and n_B is the background counting rate of 0.315 cps. The initial true counting rate n_0 was $(5.115 \pm 0.041) \times 10^4$ cps, which was determined by fitting the measured data in the low counting rate region below 70 cps, where the statistical variance weight was used for the fit.

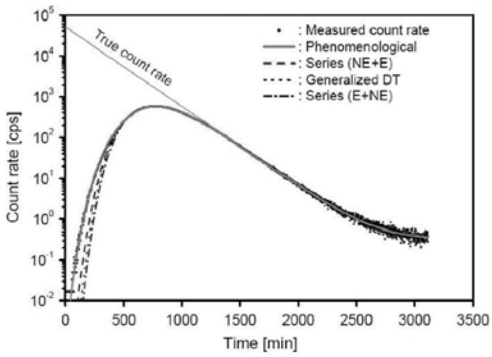

Fig. 3 Count rates measured with a GM counter and the fitted curves of various DT models for the whole range.

Table 1 The fitted results of the DT models within the whole range.

Model	τ_E [μsec]	τ_{NE} [μsec]	τ (or $\tau_E + \tau_{NE}$) [μsec]	θ	χ^2
Generalized DT	-	-	696.1 ± 1.5	0.746 ± 0.003	78.0
Series (NE+E)	399.0 ± 1.1	278.5 ± 2.0	(677.5)	-	50.5
Series (E+NE)	571.0 ± 0.7	139.2 ± 2.9	(710.2)	-	120
Phenomenological	275.9 ± 0.4	549.6 ± 3.2	(825.5)	-	4.14

Fitting to the measured data was performed using the mean count rate relations of the DT models as listed in eqs. (1)-(3). Data in the whole decaying time range were included in the fitting, and equal-weight was used for the fit.

Total DTs (τ or $\tau_E + \tau_{NE}$) obtained by the theoretical DT models were consistent within about a 10% deviation as shown in Table 1. The uncertainty of the individual DT parameters was in the order of 1%, which was due to only quoting the fitting error. When the true counting rate was below 1 kcps (i.e. $n\tau < 1$), the considered theoretical models were reduced to identical forms and the differences between the models were not apparent as shown in Fig. 3. In the higher counting rate regions, however, Figs. 3 clearly show differences between the models; furthermore, no theoretical model could explain the measured data in the high counting rate regions above 1 kcps, and the discrepancies increased at higher counting rates. Among the theoretical models considered in this study, the series NE-E DT model gave the lowest reduced χ^2 and the model rates were consistent with the data by less than 10% up to a true rate of ~10 kcps.

The phenomenological model of the mean rate eq. (4), though lacking a theoretical foundation, gives the best description of the measured data for the whole counting region as shown in Table 1 and Figs. 3. The fitting result by the empirical formula can follow, within statistical dispersions, the whole measured data including a maximum initial true counting rate of 51 kcps. The resultant total DT ($\tau_E + \tau_{NE}$) is meaningful because it is consistent within a 20% band with those obtained by other mathematical models.

5. Conclusion

The series NE-E DT model described the DT characteristics of a GM counter better than the other models. The series NE-E DT model was limited in describing the counting rates above 10 kcps. This was due to a simplified approach to the detector and counting circuits and also to a model based on two constant DTs which were independent of the true counting rates.

The present study also suggested a phenomenological formula which can sufficiently describe the measured counting rates over a counting rate range reaching a maximum of 50 kcps, even though a rigorous mathematical discussion is deficient. The obtained total DT value was reasonable when compared with the fitted values from other mathematical models, being consistent to within 20%, and gave a confident fitted result. The phenomenological model is expected to be useful for a DT correction to extend the useful range of GM counter applications.

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