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Correction of counting loss for X-ray detection system

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Introduction

The counting method is widely adopted in evaluation of X-ray beam intensities. However, the effect of counting losses due to the dead-time of the detector or the finite response time of the detection circuits may cause serious systematic errors in the evaluated intensities, especially at high count rates.

Counting losses are usually modeled by a non-extended or an extended dead-time model. The present study is intended to establish an improved method to determine the dependence of the observed count rate on the true count rate from the data measured by Chipman's foil method, and to correct the counting losses in the observed beam intensity data, allowing deviation from the non-extended or extended dead-time models.

Models for counting losses

Intermediate model

An intermediate model between the non-extended and extended dead-time models can be constructed by synthesizing the throughput functions for the two models as follows [1]:

$$n = f_{\mathrm{ex}}\left(f_{\mathrm{non-ex}}(r;\tau_1);\tau_2\right),$$

where n is the observed count rate, r the true count rate,

$$f_{\mathrm{non-ex}}(r;\tau_1) \equiv r/(1+r\tau_1)$$

is the throughput function for the non-extended model with dead-time τ_1, and

$$f_{\mathrm{ex}}(r;\tau_2) \equiv r\exp(-r\tau_2)$$

is the throughput function for the extended model with dead-time τ_2.

It will be convenient to substitute the total dead-time parameter τ and the degree of extension ρ for the parameters τ_1 and τ_2, *via* the equations:

$$\tau \equiv \tau_1 + \tau_2, \quad \rho \equiv \tau_2^2/\tau^2,$$

which gives the formula for the intermediate model:

$$f_{\mathrm{inter}}(r;\tau,\rho) = \frac{r}{1+\left(1-\sqrt{\rho}\right)r\tau}\exp\left[-\frac{\sqrt{\rho}\,r\tau}{1+\left(1-\sqrt{\rho}\right)r\tau}\right].$$

The formula exactly gives the non-extended and extended dead-time dependence for $\rho = 0$ and $\rho = 1$, respectively.

Approximation for intermediate model

An approximate formula for the intermediate model [1], which has a simple expression of its inverse function, is given by

$$n = f_{\mathrm{approx}}(r;\tau,\rho) = \frac{\exp(-r' t_2) - \exp(-2r' t_2)}{t_2}$$

$$r' = r/(1+rt_1), \quad t_1 = \tau - 3t_2/2, \quad t_2 = \sqrt{6\rho/13}\,\tau.$$

The maximum deviation of $f_{\mathrm{approx}}(r;\ \tau,\ 1)$ from $f_{\mathrm{ex}}(r;\ \tau)$ in the range $0 \le r \le 1/\tau$ is 0.0003 relative to the value $f_{\mathrm{ex}}(r;\ \tau)$ at $r = 1/\tau$, which is smaller than the statistical errors predicted for data counts up to 10^7. The inverse function of the approximate function is given by the equations

$$r = f_{\mathrm{approx}}^{-1}(n;\tau,\rho) = r'/(1-r' t_1),$$

$$r' = -\frac{1}{t_2}\ln\frac{1+\sqrt{1-4nt_2}}{2}.$$

Experimental validation

Chipman's foil method is applied to the powder diffraction intensity data of mica 003 reflection peak, measured with a high-resolution diffractometer located on BL4B2. The observed intensities are well fitted by applying the approximate intermediate model (Fig. 1), while significant deviations have been found in fitting with non-extended and extended models.

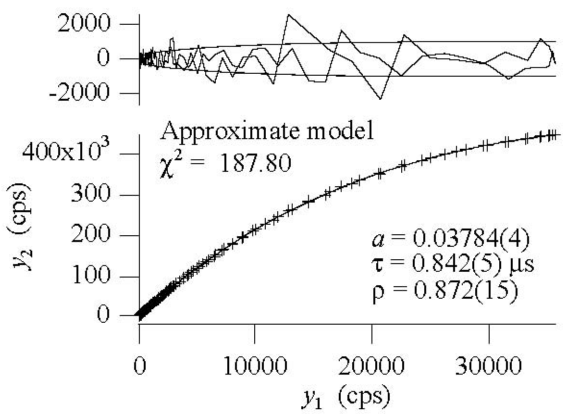

Fig. 1. Results of fitting with the approximate intermediate model, where y_1 and y_2 are attenuated and unattenuated intensities. The experimental data are shown as crosses and the optimized curve is shown as a solid line. The difference is shown as a thick line and the estimated errors ($\pm\sigma$) are shown as thin lines in the upper part.

Reference

[1] T. Ida *et al.*, *J. Appl. Cryst.* **84**, 426 (2005).

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