J. Synchrotron Rad. (1998). **5**, 851–853

Dead-time correction of a multi-element SSD for fluorescent XAFS

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(*Received 4 August 1997; accepted 21 November 1997*)

The correct evaluation of the live time of a detection system is found to be important for correcting the counting loss of a multi-element detection system for fluorescent XAFS experiments. Synchronous resetting of preamplifiers and the suspension of electronics during the reset period is an effective method. The dead time of the incoming count rate should also be corrected, since its non-linearity cannot be neglected. A 19-element solid-state detector system which can count up to 3.7×10^5 counts s^{-1} channel^{-1} with <270 eV FWHM for Mn $K\alpha$ has been realized; the dead time was independent of the incoming photon energy.

Keywords: solid-state detector systems; fluorescent XAFS; dead-time corrections; counting losses.

1. Introduction

A multi-element solid-state detector (SSD) is often used to obtain fluorescent XAFS spectra of dilute samples, thin films *etc.* (Cramer *et al.*, 1988; Derbyshire *et al.*, 1991). A high energy resolution is required in order to extract a faint fluorescent signal from intense scattering and background fluorescence signals, which is essential for improving the signal-to-noise ratio (Warburton, 1986). A high-counting-rate capability is required at the same time in order to measure a spectrum within a reasonable period. However, a high energy resolution and a high-counting-rate capability could not be realized at the same time. Reset-type preamplifiers have been developed to meet the high-counting-rate requirement without seriously sacrificing the energy resolution.

The reset rate of a preamplifier is determined by both the incoming photon flux and the photon energy (energy rate). Usually, a dead-time correction is carried out assuming that the pulse-height distribution (PHD) is independent of the counting rate. However, the PHD changes due to the sample composition and the energy of the primary X-rays in the case of fluorescent XAFS. Thus, the conventional system gave a different dead-time value under each experimental condition. A 19-element SSD with a fairly high energy resolution and high-counting-rate capability has been constructed. Its performance and a simple system designed to give a unique dead time independent of the photon energy are described.

2. Construction of the detection system

Nineteen individual pure-Ge detectors (Canberra GL0110P, 100 mm^2 each) are assembled in a cryostat. Each detector is coupled to a compact pentafet preamplifier (Nashashibi, 1992) which is essentially a low-noise device with a short reset time. The rather conventional signal-processing system consists of the following electronics: spectroscopy amplifiers (Canberra 2026XA), single-channel analysers (SCAs) (Oxford TC 452), a timing pulse generator (Kinetics 3655-L1A) and scalers (LeCroy 4434). A short shaping time, such as 0.25 µs, is usually used to meet the high counting rate. Both the SCA output and ICR (incoming count rate) pulses from amplifiers were counted in the scalers.

In order to evaluate the live time of the preamplifiers, all of the preamplifiers are reset synchronously when a reset signal is issued by a preamplifier. The timing pulse generator and scalers are also suspended during the reset period. A Kinetics 3655 was modified to realize such a function. Although the reset period is determined by the shortest one in 19 preamplifiers, this is an economical system to evaluate the live time of preamplifiers and to apply the same time gate to I_0. Furthermore, this system is free from any cross talk of the reset signal of the preamplifiers.

Fluorescence from a copper foil was detected by the SSD, whose intensity was controlled by changing the opening of a slit placed after a focusing mirror (Nomura & Koyama, 1996). Since the metal foil was placed after a 1 mm-square receiving slit, the same area was irradiated independent of the opening of the slit. The intensity of the primary X-ray was measured by an ionization chamber placed between the receiving slit and the sample, which should be proportional to the fluorescence intensity. The output of the ionization chamber was processed as usual and the output pulse of a voltage-to-frequency converter (VFC) was counted by the scaler. Higher orders were reduced to less than 10^{-6} of the fundamental by detuning a double-crystal monochromator.

3. Performance

3.1. *Performance of the detection system*

The energy resolution was measured with Mn $K\alpha$ from ^{55}Fe, for which the counting rate was ~50 kcounts s^{-1}. The average FWHM of 19 detectors was 178, 206 and 246 eV and the worst one was 193, 224 and 269 eV when the shaping time of the spectroscopy amplifiers was chosen to be 1, 0.5 and 0.25 µs, respectively.

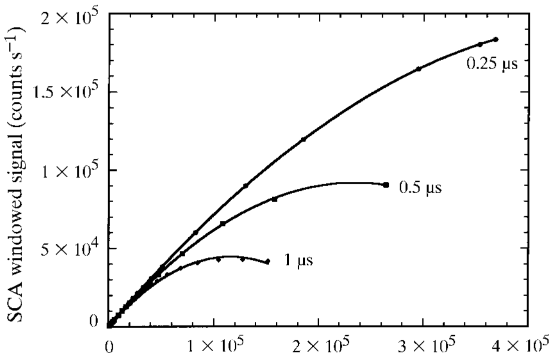

Figure 1
Relative throughput curves as functions of the shaping time and ICR. Here, the vertical axis is the signal rate passing through an SCA which is windowed for Cu $K\alpha$. The dots are the observed data and the lines are least-squares fits using equation (1). The system can count up to 370 kcounts s^{-1} for each channel when the shaping time is adjusted to 0.25 µs.

Relative throughput curves on a channel are shown in Fig. 1 as a function of the shaping time. Here, the vertical axis indicates the SCA output rate that is windowed for Cu *Kα* radiation, whereas the horizontal axis indicates ICR. Thus, the ratio of both axes does not represent the absolute throughput. The observed values (dots) were fitted well with an equation up to 370 kcounts s^{-1} when a 0.25 µs shaping time was adopted, which indicates the high counting capability of the detection system: 7 Mcounts s^{-1} for 19 channels. Details of the fitting equation are described in the next section.

3.2. *Dead-time correction*

The relative throughput curves were fitted with an equation of the first-order approximation of the paralyzable and non-paralyzable models (Zhang *et al.*, 1993). This is expressed as

$$m = \beta n(1 - n\tau_2), \tag{1}$$

where m is the apparent counting rate through an SCA window, n is the ICR, τ_2 is the usually used dead time, and β is a proportional factor which depends on the SCA window and the PHD. This equation gave a slightly better fit than those for paralyzable or non-paralyzable models. The fitted curves with this equation are shown in Fig. 1 along with the observed data, which indicate that equation (1) is a good approximation up to high counting rates. The dead time (τ_2) obtained from the fitting was 4.3, 2.1 and 1 µs for shaping times of 1, 0.5 and 0.25 µs, respectively.

The ICR is usually thought to express the true incoming rate, which is a good approximation when the shaping time is sufficiently long. However, this assumption is not correct when a short shaping time, such as 0.25 µs, is used. The ratios of ICR and I_0 were measured as a function of the counting rate. If the response of both detection systems is ideal, the ratio should be constant, independent of the counting rate. However, the ratio ICR/I_0 at ICR = 370 kcounts s^{-1} decreased by 10% compared with that at low counting rates, which indicates that the dead time of ICR cannot be overlooked. The linearity of the ionization chamber was confirmed by other experiments. Also, if it does not respond linearly and the ICR responds linearly, the ratio ICR/I_0 should increase along with an increase in the counting rate, which is contrary to the experimental result.

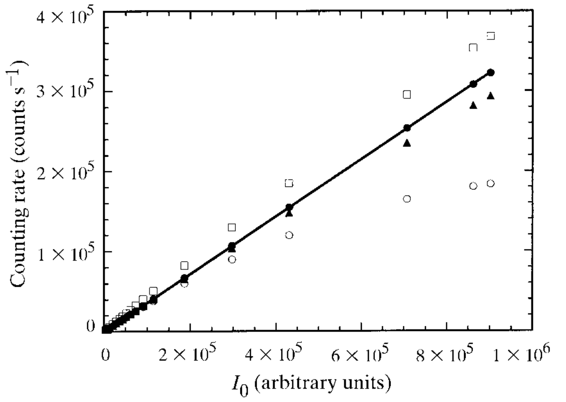

Figure 2

Response of the output signal from an SSD as a function of the incoming flux. The raw SCA output (open circles), raw ICR (open squares), dead-time corrected SCA output according to equation (4) (closed circles) and that according to equation (1) (closed triangles) are plotted. Only the closed circles show a linear response to I_0, as indicated by the straight line.

By putting the true ICR as αI_0, the apparent ICR can be expressed as

$$n = \alpha I_0(1 - \alpha I_0 \tau_1), \tag{2}$$

where I_0 is the output frequency of the VFC, τ_1 is the dead time of ICR and α is a proportional factor. By modifying the equation, I_0 can be approximated as

$$I_0 = n(1 + n\tau_1)/\alpha. \tag{3}$$

τ_1 was ~0.28 µs, which is not sufficiently short compared with τ_2.

Therefore, a correction of the dead time was carried out for both τ_1 and τ_2. The true SCA windowed signal (m_0) can be expressed as

$$m_0 = m(1 + n\tau_1)/(1 - n\tau_2). \tag{4}$$

Corrected counting rates both with and without τ_1 contribution are compared in Fig. 2. The correction, excluding the dead time of ICR (τ_1), shows a significant deviation from that including it at

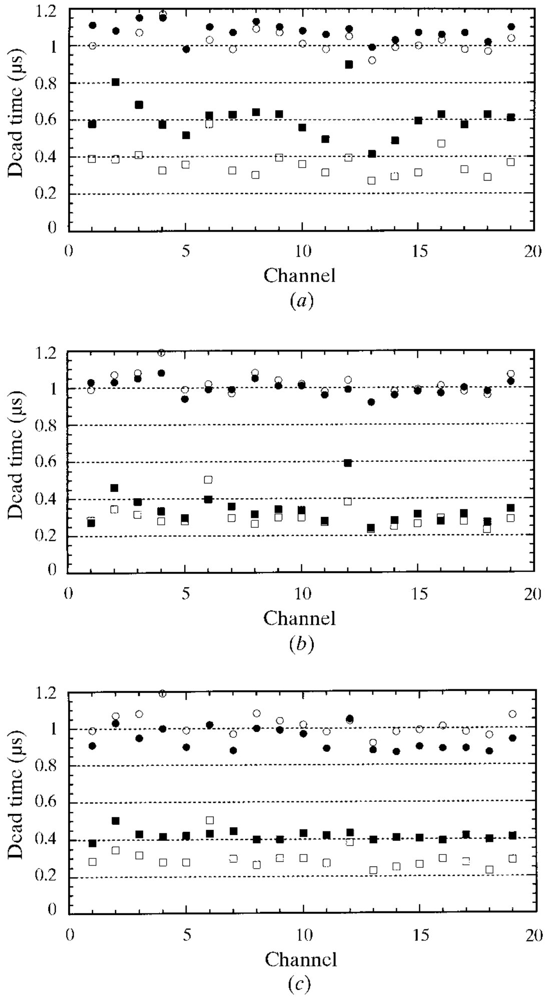

Figure 3

Dead times obtained for each channel when the photon conditions are changed. The photon energy was changed (*a*) without and (*b*) with suspending the electronics during the reset period. Here, rectangles and circles indicate τ_1 and τ_2, respectively. The open and closed symbols indicate the dead time for Cu *Kα* and Au *Lα*, respectively. The variation in the dead time by the operation mode of the storage ring is compared in (*c*). Here, the open and closed symbols indicate the dead time measured during the multi-bunch and single-bunch modes, respectively.

high counting rates, indicating the significance of the ICR dead time.

3.3. *Effect of a live-time evaluation*

In the present system, the timer and scalers were suspended during the reset period of the preamplifiers. The reset frequency of the preamplifiers is determined by the energy rate, *i.e.* the integrated photon energy in unit time. Therefore, if the live times of the preamplifiers are not correctly evaluated, the dead time for ICR (τ_1) should depend on the incoming photon energy. This is a serious problem for fluorescent XAFS experiments, since the PHD changes due to the sample composition and at each energy.

The dead time was compared using two characteristic radiations of different energies: Cu $K\alpha$ (8041 eV) and Au $L\alpha$ (9685 eV) radiation; the results are compared in Figs. 3(*a*) and 3(*b*). The dead time measured without suspending the electronics changed with the photon energy, as shown in Fig. 3(*a*). The increase in τ_1 for Au $L\alpha$ is due to an increase in the reset rate due to the higher photon energy, even at the same ICR. Another reason is that I_0 was counted during the reset period. On the other hand, those measured during suspension of the electronics did not change along with the photon energy. Similar results were obtained when both Cu $K\alpha$ and Au $L\alpha$ were detected simultaneously. It is thus important to evaluate the live time of the system correctly. In order to evaluate the live time, a synchronous reset of all the preamplifiers and suspension of the electronics during the reset period is an effective method.

3.4. *Effect of the operation mode*

The dead times obtained from equations (1)–(4) should depend on the operation mode of the storage ring. When the storage ring is operated in the single-bunch mode, it should be particularly prominent as the photons enter the detector within a short period and a fairly long recovery time is kept after that. Although the stored current was about 60 mA, which is one-sixth of that in the multi-bunch operation mode, a more than 30 times intense X-ray pulse enters the detector within 100 ps every 0.6 µs at the Photon Factory. A test experiment was carried out during single-bunch mode; the derived dead times are compared with those measured during the multi-bunch mode in Fig. 3(*c*). τ_1 increased from 0.28 to 0.39 µs, whereas τ_2 decreased from 1.0 to 0.91 µs in detector #10; the other channels showed a similar tendency. This tendency supports the above-described idea. Thus, the dead time must be obtained for each operation mode of each storage ring.

4. Conclusions

A method of evaluating the dead time, which does not depend on the photon energy, was developed by synchronous resetting of preamplifiers and suspension of the electronics. However, it is noted that the dead time changes with the operation mode of the storage ring.

The author thanks Dr Derbyshire of Daresbury Laboratory for his advise and Mr Ogasawara of Toyo Corporation and Mr Tench of Canberra for their technical support. Kinetics Co. is acknowledged for their technical advice in modifying the 3655-CAMAC module.

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