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Design issues of a chopper control system

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Abstract

The timing between a Fermi chopper in a chopper spectrometer and an accelerator is an important issue for realizing a high-resolution spectrometer. The required accuracy of the chopper control is evaluated. Also, typical timing systems for control between the chopper spectrometer and the accelerator at the existing facilities are summarized.

1. Introduction

A chopper spectrometer installed at a pulsed spallation neutron source is now widely recognized as an indispensable instrument for studies of dynamics in condensed matter, because it covers a wide energy-momentum space with reasonably good resolution. In a chopper spectrometer, a Fermi chopper is located between the neutron source and the sample to produce a monochromatic beam [1]. When the monochromatic beam is scattered by a sample, energy transfer occurs at the sample in the case of inelastic scattering. By measuring the time-of-flight (TOF) of a detected neutron, the energy transfer is determined. In the optimum design of a chopper spectrometer, the opening time width (Δt_{ch}) at the Fermi chopper is chosen to be the same as the pulse width (Δt_m) of the generated neutron; typically, 1% of the energy resolution with respect to the incident neutron energy (E_i) chosen by the Fermi chopper is realized. The pulse width depends on the neutron energy (E) and is proportional to $E^{-1/2}$ in the slowing-down region, and is typically 1 μs (full width at half maximum) for neutrons with several eV. The structure of the Fermi chopper is rotating slits, and many slits are stacked to gain the beam cross section. The opening time width of the Fermi chopper is approximately represented as $\Delta t_{ch} = w/(2\pi Df)$, where w is the width of the slit, D the diameter of the slit package, and f the rotation frequency [1]. An opening time width of $\Delta t_{ch} = 1$ μs can be realized for $w = 1$ mm, $D = 10$ cm, and $f = 10^3$ Hz. In this paper, a requirement for the accuracy of the chopper control for such a chopper spectrometer as well as a double-chopper spectrometer is described. Also, typical timing systems for control between the chopper spectrometer and the accelerator at the existing facilities are summarized.

2. Requirement on the accuracy of the chopper control

At the neutron source, neutrons with a certain energy are generated with a pulse shape, i.e., an emission time distribution, $\phi(t)$. A chopper has a window function, $w(t)$, which describes the time (t) dependence of the transmission of neutrons, and the time distribution of the transmitted beam through the chopper is given by the product of the pulse-shape function and the window function. The pulse-shape function and the window function are assumed here to be Gaussian: $\phi(t) = \exp(-t^2/2\sigma^2)/((2\pi)^{1/2}\sigma)$ and $w(t) = \exp(-t^2/2\alpha^2)$. A jitter function is introduced, which is also assumed to be Gaussian, $g(t) = \exp(-t^2/2\beta^2)/((2\pi)^{1/2}\beta)$. The jitter is the relative jitter between the neutron pulse and the chopper window, and includes the accuracy of the control of the chopper, itself, as well as the fluctuation of the repetition of the accelerator. The window function is convoluted with the jitter function, and the pulse shape multiplied by the convolution is the time distribution of the transmitted beam through the chopper. Therefore, the total intensity of the transmitted beam can be evaluated as

$$I = \int \phi(t) \int w(t')g(t'-t)dt'\,dt = \frac{\alpha}{\sqrt{\alpha^2+\beta^2+\sigma^2}}. \tag{1}$$

If the optimum condition, $\alpha = \sigma$, i.e., $\Delta t_{\mathrm{ch}} = \Delta t_{\mathrm{m}}$, is chosen, the transmitted intensity is given by $I=(2+x^2)^{-1/2}$, where x $(=\beta/\alpha)$ is the jitter with respect to the opening time width of the chopper. Figure 1 shows the transmitted intensity as a function of the jitter, $I(x)$. In order to maintain the intensity, the jitter should be kept to less than 30% of the pulse width. If neutrons with a pulse width of 1 μs are utilized, the jitter should be less than 0.3 μs.

In our future project involving the pulsed neutron source in Japan, a double-chopper spectrometer for experiments with much higher energy resolution is being proposed [2]; also, pulse shaping is possible in such a spectrometer. In a conventional chopper spectrometer having a single Fermi chopper, as discussed above, the Fermi chopper serves to choose E_{i}. However, neutrons having an energy larger than E_{i} and emitted later can pass the chopper window; such neutrons arrive at the detector earlier than those neutrons with E_{i}. Therefore, the observed TOF spectrum has a tail at the earlier TOF side (Fig.2). If a second chopper is located between the neutron source and the Fermi chopper, such a tail can be eliminated, because the two choppers define the width of the generated pulse. This concept can be applied to a higher-resolution machine. If 10% of the pulse width is defined by the two choppers, an energy resolution of 0.1% can be realized. Such a concept can be confirmed with simulations.

The transmission function of the second chopper ($w_2(t)$) and its jitter function ($g_2(t)$) are introduced, and the transmitted intensity is estimated similarly as in the conventional chopper spectrometer. The jitter function of the second chopper is defined with respect to the first chopper. These two functions are assumed to be Gaussian: $w_2(t) = \exp(-t^2/2\alpha_2^2)$ and $g_2(t) = \exp(-t^2/2\beta_2^2)/((2\pi)^{1/2}\beta_2)$. The transmitted intensity can be written as:

$$\begin{aligned} I &= \int \phi(t) \int w(t')g(t'-t) \int w_2(t'')g_2(t''-t')dt''dt'\,dt \\ &= \frac{\alpha\alpha_2}{\sqrt{(\alpha^2+\beta^2+\sigma^2)(\alpha_2^2+\beta_2^2)+\alpha^2(\beta^2+\sigma^2)}}. \end{aligned} \tag{2}$$

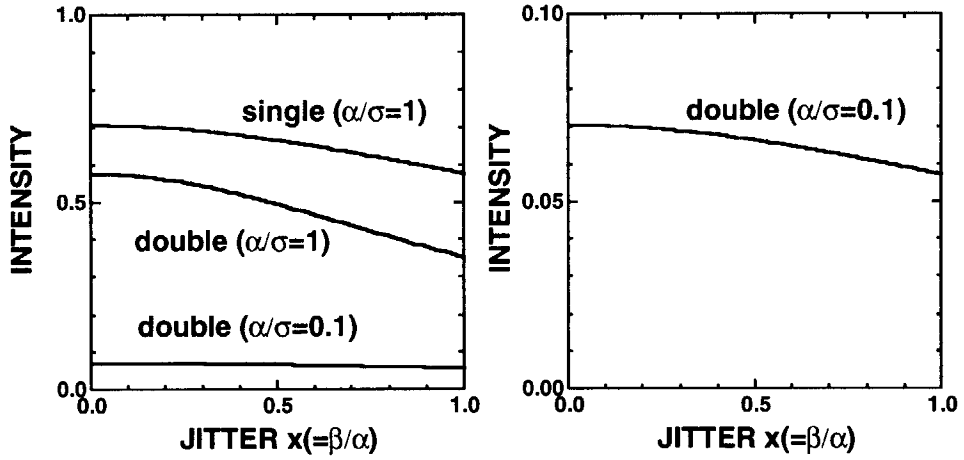

Fig.1 Intensity transmitted through the Fermi chopper as a function of the jitter of the chopper control system with respect to the opening time window of the Fermi chopper.

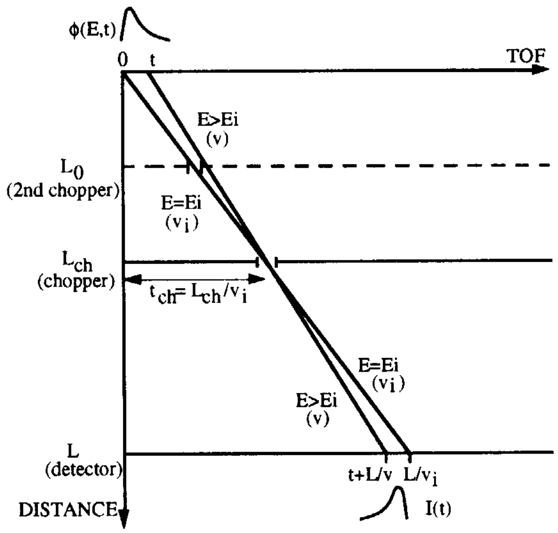

Fig. 2 Schematic diagram of the concept of a double-chopper spectrometer.

The transmitted intensity in the case of a double chopper is also plotted in Fig.1, where it is assumed that $\alpha = \alpha_2$ and $\beta = \beta_2$. The condition $\alpha/\sigma = 1$ corresponds to the optimum design of the conventional chopper spectrometer with an energy resolution of 1%, and $\alpha/\sigma = 0.1$ corresponds to a 0.1% resolution machine. In any case, in order to maintain the intensity, the jitter should be kept to less than 30% of the opening time width of the chopper.

3. Synchronization between the chopper and the accelerator

Here, two types of the existing timing systems for synchronization between the chopper and the accelerator are summarized. The repetition of the KEK-Booster Synchrotron is 50 ms and the timing accuracy of extraction is approximately 10 μs over a short period. However, the Fermi chopper on the chopper spectrometer, INC, at KENS cannot follow periodic fluctuations due to its inertia. The Fermi chopper on INC requests to extract the proton beam during the timing band where extraction of the proton beam is possible [3]. Such a system can work at a facility which has one chopper. On the other hand, ISIS has a crystal master clock. This generates an AC power of 50 Hz and the synchrotron is driven by the power with synchronizing the master clock. A master pulse is also generated from the crystal master clock, and choppers are synchronized to the stable master pulse. ISIS has three chopper spectrometers, each of which works with a good energy resolution. In our future project, we are planning to install several chopper spectrometers, as ISIS. A crystal master clock is indispensable to control the accelerator system and the chopper control system.

4. Summary

A requirement concerning the accuracy of the chopper control for a conventional spectrometer as well as a double-chopper spectrometer was evaluated by introducing a jitter function of the Fermi chopper. The jitter is the relative jitter between the neutron pulse and the chopper window, and it includes the accuracy of the control of the chopper, itself, as well as the fluctuation of the accelerator repetition. In any case, in order to maintain the intensity, the jitter should be kept to less than 30% of the chopper window width. Also, typical timing systems for the control between the chopper spectrometer and the accelerator at the existing facilities are summarized. It is noted that a crystal master clock is indispensable for installing several chopper spectrometers with good resolutions in a facility.

References

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[2] K. Ohoyama et al., proceedings of ICANS-XV.
[3] M Arai, Y. Arakida, M. Kohgi and M. Hosoda, KEK Internal 89-9 (1989).