Appl. Phys. A 74 [Suppl.], S1598–S1600 (2002) / Digital Object Identifier (DOI) 10.1007/s003390201860

Applied Physics A
Materials
Science & Processing

Proposal for a chopper spectrometer with very high energy resolution

K. Ohoyama[1,*], S. Itoh[2], T. Otomo[2], T. Osakabe[3], J. Suzuki[3], M. Matsuda[3], K. Kuwahara[4], M. Arai[2]

[1] Institute for Materials Research, Tohoku University, Sendai 980-8577, Japan
[2] Institute for Materials Structure Science, High Energy Accelerator Research Organization, Tsukuba 305-0801, Japan
[3] Advanced Science Research Center, Japan Atomic Energy Research Institute, Tokai, 319-1195, Japan
[4] Department of Physics, Tokyo Metropolitan University, Hachioji 192-0397, Japan

Received: 20 July 2001/Accepted: 3 December 2001 –

Abstract. Resolution functions of general-purpose chopper spectrometers at an intense pulsed-neutron source estimated by a Monte Carlo simulation technique are reported. The results indicate that a chopper spectrometer installed at a decoupled liquid-H_2 moderator gives an energy resolution, $\Delta\varepsilon/E_i$, of 1% when a very thin detection system is developed. We have also estimated resolution functions for a double Fermi chopper spectrometer for very high resolution measurements.

PACS: 61.12.Ex

General purpose direct geometry spectrometers with large measurable $Q-\omega$ space with good resolution are definitely important tools for investigations in wide scientific fields.

Figure 1 shows $Q-\omega$ space which will be able to be measured when a direct geometry spectrometer with a very high energy resolution, $\Delta\varepsilon/E_i$, of 0.1% is realised. As shown in Fig. 1, the spectrometer with $\Delta\varepsilon/E_i = 0.1\%$ can measure in large $Q-\omega$ space with six orders and three orders of magnitude of energy transfer and Q range, respectively, by changing incident neutron energy. For $E_i = 100$ meV, the spectrometer observes both excitations below 1 meV and around 80 meV with a resolution of 0.1% or better by *one* measurement.

In this paper, we report estimation of resolution functions of chopper spectrometers in the intense pulsed-neutron source which will be constructed under the joint project of JAERI (Japan Atomic Energy Research Institute) and KEK (High Energy Accelerator Research Organization) for high-intensity proton accelerators using Monte Carlo simulation technique, and propose possible chopper spectrometers with very high resolution. This work was done by the chopper spectrometer group (group leader : S. Itoh, KEK) in the joint project.

*Corresponding author.
(Fax: +81-22/215-2036, E-mail: ohoyama@imr.edu)

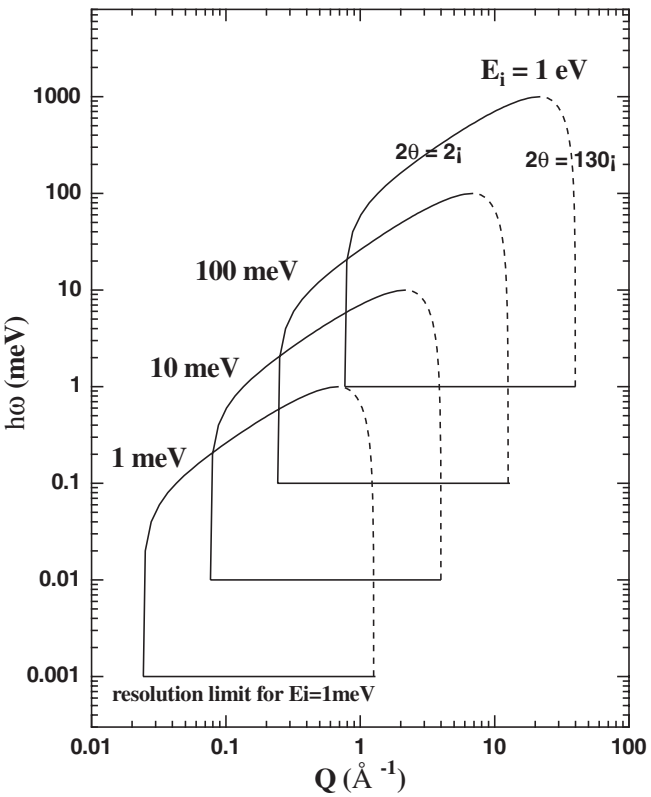

Fig. 1. $Q-\omega$ space of a chopper spectrometer with an energy resolution, $\Delta\varepsilon/E_i$, of 0.1% with different incident neutron energy. The 2θ range is from 2 deg. to 130 deg. The lowest energy boundaries are defined as resolution limits

1 Monte Carlo simulation by McStas

To estimate energy resolution and optimise parameters, we performed simulation of resolution functions of chopper spectrometers installed at a decoupled H_2 moderator in the joint project using the Monte Carlo ray-tracing simulation

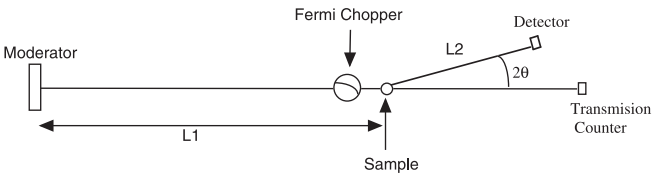

Fig. 2. Arrangement of a chopper spectrometer with a Fermi chopper for the calculations

software, McStas (ver. 1.2), written by Nielsen and Lefmann of Risϕ [1, 2]. The Ikeda-Carpenter function was used as the time structure of the neutron pulse at the moderator surface in the simulation [3]; the complete set of parameters of the Ikeda-Carpenter function for the pulse shape of the decoupled liquid H_2 moderator were already determined by the Neutron Source group and Simulation group of the joint project. Figure 2 shows the arrangement of a chopper spectrometer: L_1 is the flight length between the moderator and the sample, and L_2 is that between the sample and the detectors, 2θ is scattering angle of a detector. The detectors have a dimension of $2 \times 2\,\mathrm{cm}^2$; the thickness is assumed to be 0. Thus, a very thin detection system is expected in this paper. The sample is a vanadium rod with a diameter of 2 cm and a height of 2 cm, which has real scattering and absorption cross sections [1, 2]. The flight paths are $L_1 = 15\,\mathrm{m}$ and $L_2 = 4\,\mathrm{m}$ because the values optimise neutron flux and resolution at the detector positions [5].

At first, we confirmed that the calculated spectra at $\varepsilon = 0$ by McStas with the Ikeda-Carpenter function were well coincide with observed elastic incoherent scattering spectra obtained from a vanadium rod on the chopper spectrometer, INC, installed at KENS, KEK.

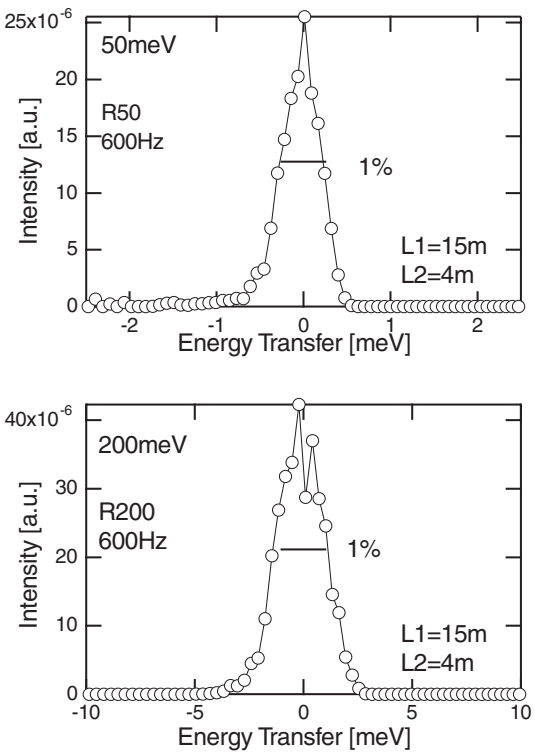

Fig. 3. Elastic incoherent scattering spectra from a vanadium rod with a diameter of 2 cm with $E_\mathrm{i} = 50$ and 200 meV calculated by McStas. In the calculation, the spectrometer is a conventional Fermi chopper spectrometer installed at a decoupled H_2 moderator in the joint project . Horizontal lines in the figures indicate $\Delta\epsilon/E_\mathrm{i}$ of 1% under each condition

Figures 3 indicate calculated elastic incoherent scattering spectra around $\varepsilon = 0$ meV on a chopper spectrometer installed at the decoupled liquid H_2 moderator of the joint project with $E_\mathrm{i} = 50$ meV and 200 meV. R50, R200 means rotors which are optimised for $E_\mathrm{i} = 50$ meV and 200 meV with a rotor frequency of 600 Hz: rotor radius, D, slit package radius, ϱ, and thickness of aluminium and boron plate, Al/B, are, $D = 125$ mm, $\varrho = 410$ mm and Al/B = 1.52 mm/0.55 mm for R50 and D = 125 mm, $\varrho = 820$ mm and Al/B = 1.14 mm/0.55 mm for R200. The horizontal lines in the figures show an energy resolution, $\Delta\varepsilon/E_\mathrm{i}$, of 1% under each condition, where $\Delta\varepsilon$ is full width at half maximum. The peak shapes in Fig. 3 are almost symmetric and a resolution of about 1% is realised, though slight tails exist in the negative energy sides which are due to asymmetric pulse shapes at the moderator in the joint project. We confirmed that a resolution of 1% is also realised for $E_\mathrm{i} = 100$ meV and 500 meV. This indicates that a conventional chopper spectrometer which will be installed at the decoupled H_2 moderator has an energy resolution of 1% at the elastic condition in wide E_i range when the spectrometer has very thin detectors.

2 Double-chopper spectrometer

As a next step, we discussed possibility of very high energy resolution experiments with a chopper spectrometer which has two Fermi choppers (double chopper), and estimated the resolution by McStas.

Figure 4 indicates the principle of the double chopper system. Vertical and horizontal axes indicate the position of each equipment and Time-of-Flight, respectively. The slant lines indicate the relation between Time-of-Flight and flight length of neutron with particular energies. As shown in the upper figure of Fig. 4, when the pulse at the moderator has a tail, it is impossible to avoid asymmetry of the pulse shape at detectors even though the chopper window is extremely narrow, because conventional chopper spectrometers detect just an opposite image of the pulse shape at the moderator.

On the other hand, as shown in the lower figure of Fig. 4, when another chopper (pre-chopper) is installed above the chopper (main chopper), the flight path is quite limited when the distance between the pre-chopper and the main chopper is large enough; only controlling the open timing of the pre-chopper, one can select any part of the pulse at the moderator with nearly the same E_i. Thus, using this double chopper system (pre chopper + main chopper), users can obtain resolution function with highly symmetric time structure at detector positions even though the neutron pulse at the moderator has a long tail.

Figures 5 show some results of simulations of the resolution function on a spectrometer with the double chopper system obtained by McStas. For the simulations, we used parameters of pulse shapes of the H_2O moderator without poisoning of KENS, KEK instead of the decoupled H_2 moderator in the joint project because the broad and asymmetric pulse shapes on the moderator of KENS is more suitable for check of efficiency of the double chopper system. In the calcula-

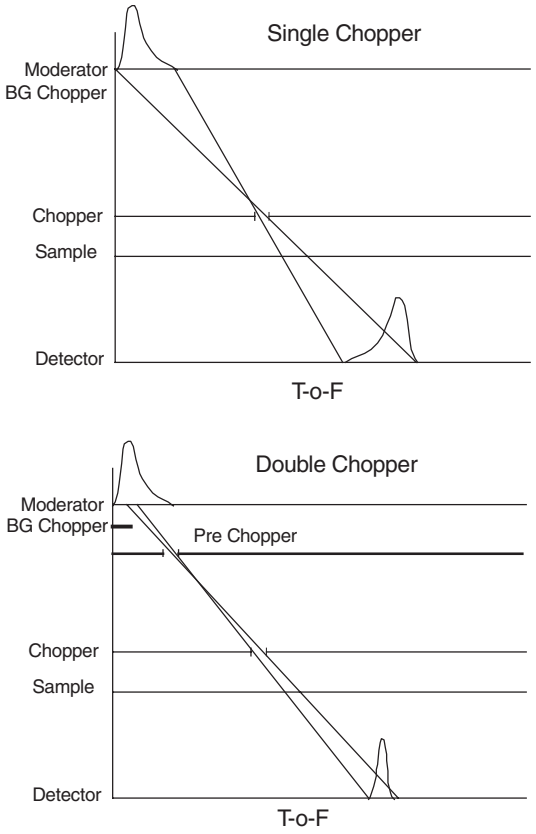

Fig. 4. Time-of-Flight relation of a conventional single chopper spectrometer (*upper*) and a chopper spectrometer with the double chopper system (*lower*). BG Chopper and Pre Chopper mean a background chopper and the second chopper installed above the main chopper, respectively

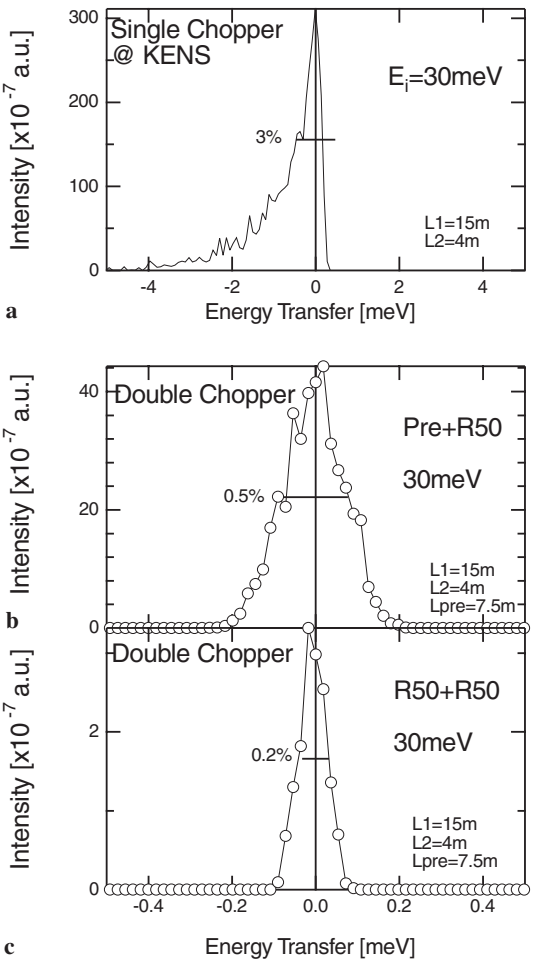

Fig. 5. Effect of the double chopper system installed at the H_{20} moderator without poisoning at KENS of KEK with $E_i = 30$ meV. **a** shows a calculated spectrum at $\varepsilon = 0$ meV from a vanadium rod by a conventional single chopper spectrometer, **b** and **c** show those by a chopper spectrometer with the double chopper system. The slit width, ω, of the pre-chopper for the calculations in **b** and **c** is 3 mm and 1.52 mm, respectively

tions, the detector thickness was assumed to be 0. Figure 5a indicates the resolution function of a single chopper spectrometer at the elastic condition for $E_i = 30$ meV; resolution is about 3% with obvious asymmetry due to the asymmetric pulse shape on the moderator. Figure 5b and c show spectra obtained by a spectrometer with the double chopper system with the same parameters of the pulse shape at the moderator as those in Fig. 5a. The distance from the moderator and the pre-chopper, L_{pre}, was fixed to be 7.5 m, and the rotor of the main-chopper was R50 with $\omega = 1.52$ mm, in the calculations.

Figure 5b shows the result for the pre-Fermi chopper with a slit width of 3 mm; $\Delta\varepsilon/E_i$ is about 0.5% without the obvious asymmetry, even in the case that the time structure of the pulse at the moderator has a large tail. Moreover, even $\Delta\varepsilon/E_i = 0.2\%$ are realised when the slit width of the pre-chopper is 1.52 mm as shown in Fig. 5c, though loss of beam flux is serious. Optimisation of rotor parameters, ω, ϱ, must give higher intensity and better resolution. To obtain high intensity at detectors, one solution is that the spectrometers should be installed at coupled H_2 moderators which have large flux and broad pulse shapes, because the double chopper spectrometers can avoid influence of the large tails at the moderators.

We think that the results indicate that high energy resolution must be feasible by optimising parameters of the double chopper system in the joint project in Japan, when a very thin detector with high efficiency is developed. To avoid fatal intensity loss by the double chopper system, more detailed and systematic simulation to find best parameters is in progress.

References

1. McStas WWW home page: http: //neutron.risoe.dk/mcstas/.
2. K. Lefmann, K. Nielsen, *McStas, a general software package for neutron ray-tracing simulations*, Neutron News **10**/**3**, 20 (1999).
3. S. Ikeda, J. Carpenter: Nucl. Instr. and Meth. **A239**, 536 (1985).
4. see for instance, KENS Report-VII **88-2**, 9 (1988), and references therein.
5. K. Ohoyama, Proceedings of the 5th Meeting of the International Collaboration on Advanced Neutron Sources, ICANS-XV **1**, 418 (2001).