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Chopper layout for spectrometers at long pulse neutron sources

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ABSTRACT

We discuss the implications of a long pulse neutron source for the chopper system of direct geometry time-of-flight spectrometers. While the same conditions apply for the layout of the resolution defining choppers as on reactor based instruments, we emphasize the multi-chromatic nature of the instruments. The chopper system must not only provide a unique assignment of the wavelength to each pulse, but also provide adopted time frames matching the respective energy of the pulse. We propose a chopper system consisting of disc choppers, heavy T0 choppers and a newly developed Fan chopper to account for the various challenges due to the long pulse nature.

1. Introduction

Direct geometry neutron time-of-flight spectrometers have been used traditionally for high resolution studies of self-correlation functions and local excitations, which give rise to scattering into a large solid angle. These and similar studies do not require high momentum space resolution due to the small dispersion and therefore the instrument can measure the scattering signals with a high efficiency by large solid angle coverage of the detector. For the measurements of coherent inelastic scattering traditionally three axis neutron spectroscopy has been employed. With the development of large position sensitive detectors and the improvement of the instrument brilliance it became possible to map the reciprocal space of single crystalline samples efficiently with chopper spectrometers thanks to the large detector coverage. The most prominent early example of this application is the MAPS spectrometer at the short pulse spallation source ISIS, which was followed by instruments at the new MW spallation sources SNS and J-Parc. These instruments benefit from the high peak brilliance of the source. Due to the short neutron pulses the time-of-flight resolution is extremely good. The latest generation of reactor based time-of-flight spectrometers has adopted the mapping capabilities. The lower peak flux of the moderator spectrum is partly compensated by higher measurement frequencies or repetition rate as compared to the spallation source, at least for moderate resolution requirements. While at steady sources repetitions rates up to 1000 Hz can be realized, spallation sources typically run at frequencies from 10 to 60 Hz. The frequency limitation has been overcome by multi-chromatic use of the spallation source, sometimes called the Repetition Rate Multiplication (RRM) [1] or Multiple E_i method [2]. At the future long pulse spallation source ESS, the multi-chromatic methods have to be explored for all instruments in order to use the neutrons from the source efficiently and explore the potential gain in instrument performance due to the increased peak brightness. In this paper we describe the implications on the chopper system for the multi-chromatic operation. It is organized as follows: first we review the relationship between energy resolution and intensity with respect to the requests for the chopper system. Then we discuss the novel challenges for an improved multi-chromatic operation. We briefly discuss the problem of the long pulse in terms of background and the layout of a T0 chopper. Finally we conclude with recommendations for the layout of chopper systems serving different applications.

2. Energy resolution

In direct geometry time-of-flight spectroscopy the neutron velocity is selected by the M chopper (counter rotating chopper pair) that transmits only the neutrons of a pulse, that have the desired velocity. The neutron pulse itself can be formed either by the source as in the case of a short pulse spallation source or by (pair of) choppers as on reactor based TOF spectrometers, the so-called P chopper. The generic layout of a direct geometry time-of-flight spectrometer for a reactor source and also for a long pulse source is shown in Fig. 1.

The energy resolution can be calculated from the apparent time spread due to the finite pulse width τ_P and τ_M at the P chopper and the M chopper, respectively. While these two contributions to the energy resolution are experimentally controlled by the

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chopper system, flight path uncertainties due to the spatial extension of the neutron beam and the sample and due to the time and the position of the neutron detection have to be taken into account [3,4].

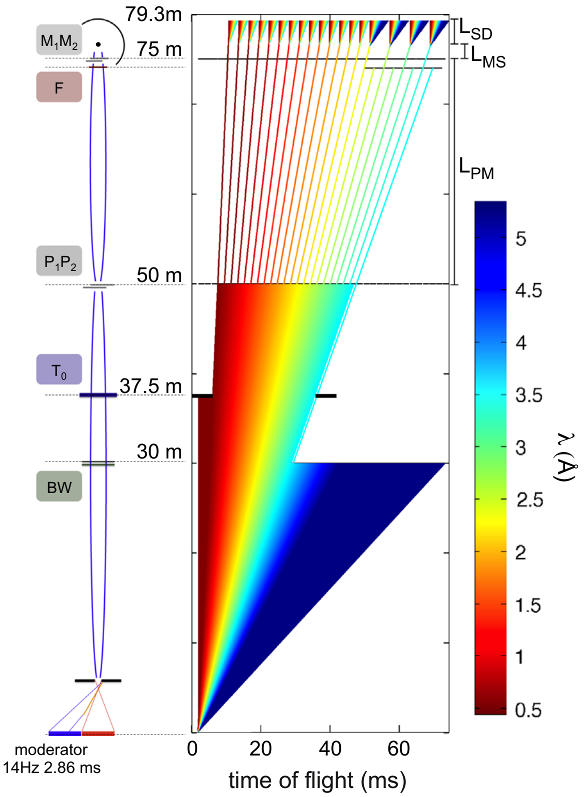

Fig. 1. Generic layout of a chopper spectrometer and a schematic flight path diagram showing the action of the choppers for a total instrument length $L_{\mathrm{Det}} = 79.3$ m. Neutrons are emitted from the moderator during the pulse length of the source. Different colors code the neutron wavelength before and after scattering λ and λ', respectively. The initial λ is calculated using the emission time at the moderator, from which the P and M choppers accept neutrons. For a discussion of the consequences of the extended pulse see Figs. 3, 4 and 6. The neutron pulse is shaped by the P chopper and a narrow velocity/wavelength distribution is selected by the M chopper. The additional choppers avoid cross-talk between the different chopper/source pulses (bandwidth choppers 'BW'), time frame overlap (the newly developed fan chopper 'F' consisting of multiple blades) and block the direct line-of-sight, when the proton pulse interacts with the target (T0 chopper). (For interpretation of the references to color in this figure caption, the reader is referred to the web version of this paper.)

$$\Delta E = \frac{h^3}{m_n^2} \frac{\sqrt{A^2+B^2+C^2}}{\lambda'^3 L_{\mathrm{SD}} L_{\mathrm{PM}}} \tag{1}$$

$$A = \tau_{\mathrm{M}}(L_{\mathrm{PM}} + L_{\mathrm{MS}} + (\lambda'/\lambda)^3 L_{\mathrm{SD}}) \tag{2}$$

$$B = \tau_{\mathrm{P}}(L_{\mathrm{MS}} + (\lambda'/\lambda)^3 L_{\mathrm{SD}}) \tag{3}$$

$$C = \frac{m_n}{h} L_{\mathrm{PM}} \cdot \lambda' \cdot \Delta L \tag{4}$$

with λ, λ' representing the neutron wavelength before and after scattering at the sample, respectively. The different flight paths are introduced in Fig. 1. τ_{P} and τ_{M} give the opening times of the P and M chopper, respectively. Also the intensity I that passes through a chopper system is proportional to the pulse width and the geometry of the instrument

$$I \propto \frac{\tau_{\mathrm{P}} \tau_{\mathrm{M}}}{L_{\mathrm{PM}} L_{\mathrm{SD}}}. \tag{5}$$

The optimization of the energy resolution under the additional condition of maximized intensity relates the burst times of the P and M choppers, respectively:

$$\tau_{\mathrm{P}} = \tau_{\mathrm{M}} \left(\frac{L_{\mathrm{PM}}}{L_{\mathrm{MS}} + (\lambda'/\lambda)^3 L_{\mathrm{SD}}} + 1 \right) \tag{6}$$

i.e. when the uncertainty contributions A and B are equal.

In the flight path diagram Fig. 1 the chopper openings $\tau_{\mathrm{P}}, \tau_{\mathrm{M}}$ and the distance between the choppers L_{PM} determine the velocity distribution, which can pass through the chopper system. Also the energy transfer resolution is completely determined by the P and M chopper system, if the appropriate flight path uncertainties are taken into account. We emphasize here that the contribution of the flight path uncertainty is directly proportional to the final wavelength λ'. If the final wavelength is short, this contribution can therefore be neglected while it becomes dominating for long wavelength. Particularly for thermal neutrons and for neutron energy gain processes short pulses define therefore the performance of the instrument. For long final neutron wavelength λ' it is however necessary to keep the flight path uncertainties as small as possible. From Eq. (6) we see that the requirements on the P chopper burst time are more relaxed than the requirements on the M chopper, if the distance between the choppers is significantly larger than the sample-to-detector distance L_{SD} and the monochromator-to-sample distance L_{MS}. The major technological challenge is therefore the matching of the M chopper contribution and the flight path uncertainties. Using counter rotating chopper pairs and multi-slit configurations [5] as used on the LET

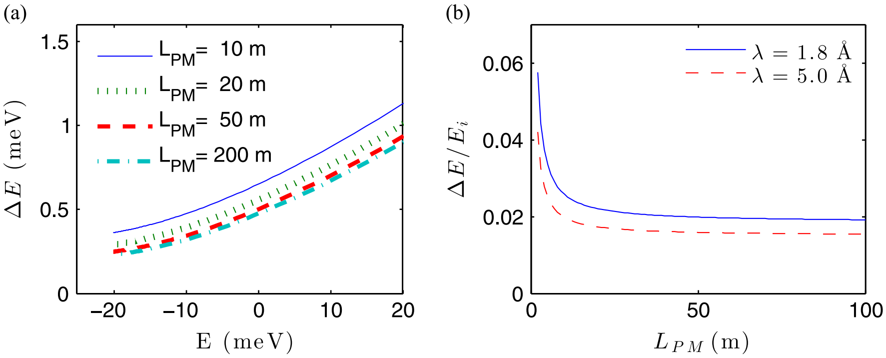

Fig. 2. (a) Energy resolution for different distances L_{PM} for balanced P and M choppers, assuming a flight path uncertainty $\Delta L = 20$ mm. The initial wavelength is $\lambda = 1.8$ Å. (b) Energy resolution for $\hbar\omega = 0$ meV as a function of chopper distance L_{PM} for different initial wavelengths λ, $\tau_{\mathrm{M}} = 10, 20$ μs for the short and long wavelength, respectively. The flight path uncertainty is $\Delta L = 20$ mm as in (a).