On Chopper Spectrometer Options for the ESS

Resolution

The energy resolution at the elastic line of a chopper spectrometer is given by

$$\frac{\Delta e}{E_i} = 8.7478x10^{-4} \frac{\sqrt{E_i(meV)}}{L_2(m)} \Delta t(ms) \qquad (1)$$

where L_2 is the flight path between the sample and the detector and Δt is the pulse width at the detector. Δt comprises a component (Δt_{md}) arising from the moderator pulse width at the detector and a component from the chopper pulse width at the detector (Δt_{cd}).

We can consider the two components as follows assuming we are restricting the discussion to elastic scattering for the time being for the sake of simplicity.

$$\Delta t_{md} = \frac{L_2 + L_3}{L_1} \Delta t_{mm} \qquad (2)$$

$$\Delta t_{cd} = \frac{L_2 + L_1 + L_3}{L_1} \Delta t_{cc} \qquad (3)$$

Δt_{md} and Δt_{mm} is the moderator pulse width at the detector and the moderator pulse width at the moderator respectively. Similarly, Δt_{cd} and Δt_{cc} represent the chopper pulse width at the detector and at the chopper. L_1 is the moderator to chopper distance and L_3 the chopper to sample distance.

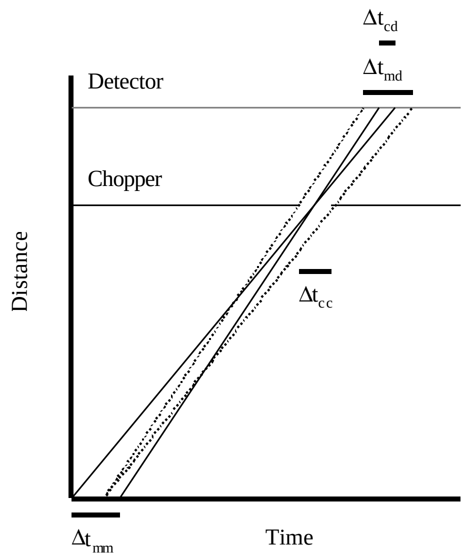

Figure 1. *Distance time plot for a chopper spectrometer.*

Clearly, to optimise resolution L_2 is made as long as possible. The only limit being the expense of large detector arrays and the availability of space. For high incident energies large portions of Q space can be accessed at relatively low angles, at thermal to low energies however large detector areas are important to provide reasonable Q coverage.

In considering the optimal configuration for a chopper spectrometer one can calculate the minimum value of L_1 which will give the desired resolution for the given moderator pulse width. We assume the resolution is dominated by the moderator contribution, therefore

$$\frac{\Delta e}{E_i} = 8.7478x10^{-4} \frac{\sqrt{E_i}}{L_1} \Delta t_{mm} \left(1 + \frac{L_3}{L_2}\right). \qquad (4)$$

Table 1 gives the minimum values of L_1 required to give a minimum (i.e. best) resolution of 1% and 2% for a range of energies for the poisoned de-coupled, un-poisoned de-coupled, and coupled ambient water moderators respectively.

2% Energy resolution	Ei (meV)	Decoupled poisoned	Decoupled unpoisoned	Coupled
	10	3.4	5.5	12.3
	20	4.9	7.7	17.4
	50	7.2	11.7	26.0
	75	7.6	12.6	26.1
	100	7.1	12.1	22.3
	150	5.7	9.9	14.7
	200	4.7	8.0	10.3
	250	4.0	6.8	7.9
	300	3.5	5.9	6.4
	600	2.4	3.8	3.5

1% Energy resolution	Ei (meV)	Decoupled poisoned	Decoupled unpoisoned	Coupled
	10	6.9	10.9	24.6
	20	9.7	15.5	34.8
	50	14.4	23.3	51.9
	75	15.1	25.2	52.2
	100	14.2	24.2	44.7
	150	11.4	19.8	29.4
	200	9.3	16.1	20.6
	250	7.9	13.5	15.8
	300	7.0	11.8	12.8
	600	4.8	7.7	7.0

Table 1. Minimum moderator-chopper distances (m) required to achieve 2% and 1% energy resolution when viewing three types of ambient water moderator.

Flux

The flux at the sample for a given incident energy is proportional to the solid angle of the moderator as seen by the sample and the open time of the chopper as a fraction of the flight-time from moderator to chopper.

$$\Phi = \left(\frac{p}{d}\right)\left(\frac{WmHm}{(L_1 + L_3)^2}\right)\left(\frac{\Delta t_{cc}}{L_1}\right) \qquad (5)$$

The term (p/d) refers to the ratio of the width of the chopper transmitting slits to the width of the absorbing slats. For high incident energies supermirrors will not reduce the $(L_1+L_3)^2$ flux loss. It is clear that to optimise flux L_1 should be as short as possible (10m is the practical minimum allowing for choppers etc.) and consequently the de-coupled poisoned moderator provides acceptable resolution. The Fermi chopper is a source of background, so L_3 should be sufficiently long so as to remove the chopper from the direct line of sight of the detectors. As stated earlier L_2 should be as long as reasonably possible, consistent with the desired detector solid angle and practical and financial constraints.

The use of supermirror guides do however offer advantages at thermal energies and below, allowing L_1 to be longer without incurring the L^2 flux penalty. This raises the possibility of viewing an un-poisoned moderator or a coupled moderator and using rep. rate multiplication techniques.

If we consider a perfect guide, with a transmission of one for all the incident energies under consideration, it can be seen from equation 4 that the to maintain constant resolution L_1 will scale with Δt_{mm}. The second term from equation 5 remains despite the installation of the guide, consequently in order to gain from moving to a broader moderator, the gain in flux

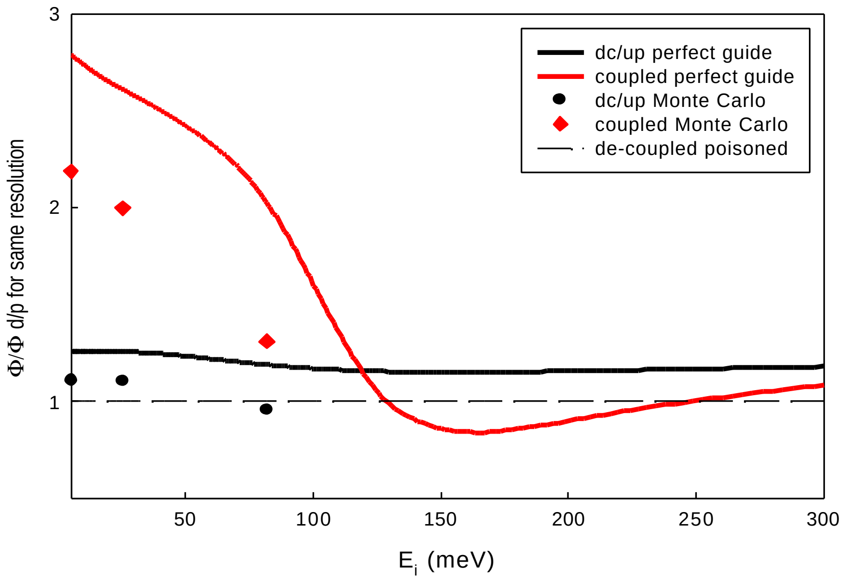

Figure 2. Ratio of flux available from the de-coupled un-poisoned moderator and the coupled moderator to the de-coupled poisoned moderator as a function of temperature, for a perfect guide and based on Monte Carlo simulations of an m=3 converging guide.

must be greater than the increase in peak width. Figure 2 illustrates the gain that might be achieved in moving from a poisoned de-coupled moderator to an un-poisoned de-coupled moderator or a coupled moderator. In reality of course guides are not perfect. Monte Carlo simulations have been performed for appropriate lengths of converging m=3 guide at three energies. These points are also plotted on figure 2. One further point to bear in mind is that a portion of the additional intensity from the coupled moderator is in a long tail. This has the effect of degrading the resolution. To preserve the resolution, a pulse-shaping chopper may be used which will chop out a portion of the additional flux that could be as much as one third. The chopper opening time can also be relaxed as L_1 is increased, but this will only provide a negligibly small increase in flux.

From figure 2 it is clear that the de-coupled un-poisoned moderator offers only marginal benefits over the de-coupled poisoned moderator, below ~50meV. The coupled moderator on the other hand offers a flux enhancement for incident energies below 100 meV that rises to approximately a factor of two at 10meV. Further, the additional length of the instrument make pulse rate replication[i] more feasible.

Summary

For high-energy spectroscopy L_1 should be as short as possible and L_2 as long as possible consistent with the desired solid angle. The de-coupled poisoned moderator is required
For thermal neutron spectroscopy, the de-coupled un-poisoned moderator can offer marginal flux enhancement below 50 meV.
A coupled moderator offers better flux for energies up to 100meV than can be achieved at equivalent resolution viewing the de-coupled poisoned moderator.

The later option also offers the capability of rep rate multiplication.
A tail cutting chopper will almost certainly need to be used on a spectrometer viewing a coupled moderator.
Position sensitive detectors are essential on all instruments.
All these instruments are well suited to a 50Hz source.
Chopper spectrometers on the ESS will out-perform all present state-of-the-art instruments on any source.

Acknowledgements
We have drawn extensively from pervious ESS studies [ii] and benefited greatly from conversations with colleagues at several of Europe's neutron centres.

[i] M Russina et al, ICANS XV Proc. (2001)
[ii] U. Steigenberger (ed.), 'Contributions to the ESS Instrument Working Group on Single Crystal Spectroscopy', ESS 98-74-T (1998).