International Tables for Crystallography (2006). Vol. C, Section 4.4.2.8, p. 443.

Historically, the first flippers used were radio-frequency coils set in a homogeneous magnetic field. These devices are wavelength dependent, but may be rendered wavelength independent by replacing the homogeneous magnetic field with a gradient field (Egorov, Lobashov, Nazarento, Porsev & Serebrov, 1974).

In some devices, the flipping action can be combined with another selection function. The wavelength-dependent magnetic wiggler flipper proposed by Agamalyan, Drabkin & Sbitnev (1988) in combination with a polarizer can be used as a polarizing monochromator (Majkrzak & Shirane, 1982). Badurek & Rauch (1978) have used flippers as choppers to pulse a polarized beam.

In neutron resonance spin echo (NRSE) (Gähler & Golub, 1987), the precession coil of the conventional spin-echo configuration is replaced by two resonance spin flippers separated by a large zero-field region. The radio-frequency field of amplitude B_1 is arranged orthogonal to the DC field, B_0, with a frequency $\omega = \omega_L$, and an amplitude defined by the relation $\omega_1 \tau = \pi$, where τ is the flight time in the flipper coil and $\omega_1 = \gamma B_1$. In this configuration, the neutron spin precesses through an angle π about the resonance field in each coil and leaves the coil with a phase angle φ. The total phase angle after passing through both coils, $\varphi = 2\omega L/v$, depends on the velocity v of the neutron and the separation L between the two coils. Thus, compared with conventional NSE, where the phase angle comes from the precession of the neutron spin in a strong magnetic field compared with a static flipper field, in NRSE the neutron spin does not precess, but the flipper field rotates. Effectively, the NRSE phase angle φ is a factor of two larger than the NSE phase angle for the same DC field B_0. Furthermore, the resolution is determined by the precision of the RF frequencies and the zero-field flight path L rather than the homogeneity of the line integral of the field in the NSE precession coil.

4.4.2.8. *Mechanical choppers and selectors*

Thermal neutrons have relatively low velocities (a 4 Å neutron has a reciprocal velocity of approximately 1000 $\mu\text{s}\,\text{m}^{-1}$), so that mechanical selection devices and simple flight-time measurements can be used to make accurate neutron energy determinations.

Disc choppers rotating at speeds up to 20 000 revolutions per minute about an axis that is parallel to the neutron beam are used to produce a well defined pulse of neutrons. The discs are made from absorbing material (at least where the beam passes) and comprise one or more neutron-transparent apertures or slits. For polarized neutrons, these transparent slits should not be metallic, as the eddy currents in the metal moving in even a weak guide field will strongly depolarize the beam. The pulse frequency is determined by the number of apertures and the rotation frequency, while the duty cycle is given by the ratio of open time to closed time in one rotation. Two such choppers rotating in phase can be used to monochromate and pulse a beam simultaneously (Egelstaff, Cocking & Alexander, 1961). In practice, more than two choppers are generally used to avoid frame overlap of the incident and scattered beams. The time resolution of disc choppers (and hence the energy resolution of the instrument) is determined by the beam size, the aperture size and the rotation speed. For a realistic beam size, the rotation speed limits the resolution. Therefore, in modern instruments, it is normal to replace a single chopper with two counter-rotating choppers (Hautecler *et al.*, 1985; Copley, 1991). The low duty cycle of a simple disc chopper can be improved by replacing the single slit with a series of slits either in a regular sequence (Fourier chopper) (Colwell, Miller & Whittemore, 1968; Hiismäki, 1997) or a pseudostatistical sequence (pseudostatistical chopper) (Hossfeld, Amadori & Scherm, 1970), with duty cycles of 50 and 30%, respectively.

The Fermi chopper is an alternative form of neutron chopper that simultaneously pulses and monochromates the incoming beam. It consists of a slit package, essentially a collimator, rotating about an axis that is perpendicular to the beam direction (Turchin, 1965). For optimum transmission at the required wavelength, the slits are usually curved to provide a straight collimator in the neutron frame of reference. The curvature also eliminates the 'reverse burst', *i.e.* a pulse of neutrons that passes when the chopper has rotated by 180°.

A Fermi chopper with straight slits in combination with a monochromator assembly of wide horizontal divergence can be used to time focus a polychromatic beam, thus maintaining the energy resolution while improving the intensity (Blanc, 1983).

Velocity selectors are used when a continuous beam is required with coarse energy resolution. They exist in either multiple disc configurations or helical channels rotating about an axis parallel to the beam direction (Dash & Sommers, 1953). Modern helical channel selectors are made up of lightweight absorbing blades slotted into helical grooves on the rotation axis (Wagner, Friedrich & Wille, 1992). At higher energies where no suitable absorbing material is available, highly scattering polymers [poly(methyl methacrylate)] can be used for the blades, although in this case adequate shielding must be provided. The neutron wavelength is determined by the rotation speed, and resolutions, $\Delta\lambda/\lambda$, ranging from 5% to practically 100% ($\lambda/2$ filter) can be achieved. The resolution is fixed by the geometry of the device, but can be slightly improved by tilting the rotation axis or relaxed by rotating in the reverse direction for shorter wavelengths. Transmissions of up to 94% are typical.

4.4.3. Resolution functions (By R. Pynn and J. M. Rowe)

In a *Gedanken* neutron scattering experiment, neutrons of wavevector $\mathbf{k}_I$ impinge on a sample and the wavevector, $\mathbf{k}_F$, of the scattered neutrons is determined. A number of different types of spectrometer are used to achieve this goal (*cf.* Pynn, 1984). In each case, finite instrumental resolution is a result of uncertainties in the definition of $\mathbf{k}_I$ and $\mathbf{k}_F$. Propagation directions for neutrons are generally defined by Soller collimators for which the transmission as a function of divergence angle generally has a triangular shape. Neutron monochromatization may be achieved either by Bragg reflection from a (usually) mosaic crystal or by a time-of-flight method. In the former case, the mosaic leads to a spread of $|k_I|$ while, in the latter, pulse length and uncertainty in the lengths of flight paths (including sample size and detector thickness) produce a similar effect. Calculations of instrumental resolution are generally lengthy and lack of space prohibits their detailed presentation here. In the following paragraphs, the concepts involved are indicated and references to original articles are provided.

In resolution calculations for neutron spectrometers, it is usually assumed that the uncertainty of the neutron wavevector does not vary spatially across the neutron beam, although this reasoning may not apply to the case of small samples and compact spectrometers. To calculate the resolution of the spectrometer in the large-beam approximation, one writes the measured intensity I as

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