AN ALTERNATIVE METHOD OF DETERMINING THE CHOPPER TRANSMISSION FUNCTION

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A method of determining the transmission function of a curved-slit slow neutron chopper by using monoenergetic neutron beams is described. The transmission function is determined directly from the time-of-flight spectra measurements, performed at several chopper speeds, of a monoenergetic neutron beam obtained by the use of a mica crystal as a sample. This method allows the experimental determination of the transmission function for the two chopper opening positions, $0°$ and $180°$, simultaneously.

1. General

In neutron spectrometry, concerning the utilization of neutron beams from nuclear research reactors, there are essentially two methods to determine the energy of neutrons, namely (1) by determining their velocity in the time-of-flight technique and (2) by determining their wavelength in the crystal spectrometer technique. This paper describes a method of measuring the transmission function of a time-of-flight instrument based on a combination of both techniques.

The principle of operation of the slow-chopper time-of-flight spectrometer is well known and has been described by many authors [1–4]. A neutron chopper is essentially a rotating collimator that converts a continuous neutron beam into a pulsed one. Each pulse or burst is formed by neutrons having several different velocities. The time required for these neutrons to reach a detector located at a known distance from the chopper is measured electronically. A magnetic pick-up connected to the rotating chopper provides a signal each time a neutron burst is formed at the center of the rotor. This signal determines the zero of the time scale by triggering an electronic clock or multichannel time analyser that accumulates counts in different channels corresponding to different neutron velocities.

The operation of the crystal spectrometer is based on a different principle. It utilizes the selective diffraction from a single crystal governed by the Bragg equation for coherent elastic scattering, which is given by $\lambda = (2d \sin \theta)/n$, with $n = 1,2,3,\cdots$, where n is the order of reflection, λ is the neutron wavelength, d is the spacing of the appropriate crystal planes and θ is the glancing angle of the neutron beam with respect to these planes. The various neutron wavelengths are selected by chang-

ing the Bragg angle θ. Since any neutron which satisfies the equation can be diffracted, higher order contamination is always present in the reflected beam which has neutrons with the desired wavelength λ and also wavelengths $\lambda/2$, $\lambda/3$, $\cdots$. Polycrystalline filters that transmit only neutrons with wavelengths greater than the cut-off given by twice the largest interplanar spacing, are commonly used to eliminate or attenuate higher order contamination.

The method of determining the transmission function of a chopper developed in the present work uses a mica crystal as a sample that, by means of coherent elastic scattering, diffracts a monoenergetic neutron beam in a certain angle of scattering in which the time-of-flight spectrometer is positioned. In this diffracted beam are present only neutrons with the desired wavelength λ, since higher order contaminations are eliminated by using a beryllium polycrystalline filter.

By chopping the Bragg diffracted beam that has approximately a narrow Gaussian shape and by time-of-flight analyzing the resulting neutron burst, it has been possible to measure a transmitted neutron spectrum with two peaks for each defined chopper speed, relative to the two chopper openings: the $180°$ position and the $0°$ position. The procedure is equivalent to installing the chopper on the arm of a crystal spectrometer.

Then, by varying the chopper speed while keeping constant the neutron wavelength of the diffracted beam provided by the mica crystal, a chopper transmission curve can be achieved. These data are essential in the corrections of the experimental neutron scattering spectra, so it is of fundamental importance for operating the time-of-flight spectrometer [5–7].

2. The spectrometer

The IPEN conventional cold neutron time-of-flight spectrometer [5,6] is in operation at the IEA 2 MW swimming pool research reactor for neutron inelastic scattering measurements. A polycrystalline beryllium filter cooled with liquid nitrogen transmits a neutron spectrum with a sharp cut-off at 3.96 Å (5.2 meV) and with a mean energy of 3.5 meV and a width of 2 meV; a Pb monocrystal filter is used to reduce the γ-ray background. Neutrons scattered by the sample at a certain angle are pulsed by a curved slit slow neutron chopper operated usually at 220 rps and are detected by a bank of ^{3}He detectors after an evacuated flight path of 3.15 m. Scattered neutron spectra are recorded with a multichannel time-of-flight analyzer and the time-of-flight resolution is 1.7% for 4.0 Å neutrons and 6.4% for 1.0 Å neutrons.

The chopper [4] consists essentially of a cylindrical rotor of radius $r = 5$ cm and length 14 cm, which contains nine cadmium covered steel plates 0.5 mm thick separated by aluminium spacers forming 10 curved slits of width $2d = 0.3968$ cm and nominal radius of curvature $R_0 = 74.5$ cm. The chopper total opening is 11 cm × 4.5 cm. The remaining volume of the cylinder is filled with B_4C mixed with araldite in approximately equal amounts. A universal electric motor connected by elastic coupling to the rotor axis can rotate the chopper with speeds up to 250 rps.

An electromagnetic pick-up provides a signal for each chopper revolution. A pulse shape circuit triggered by the pick-up signal gives the pulse that is utilized to start the multichannel analyzer. The pick-up position can be manually adjusted, so that the rotating magnet passes right in front of the fixed pick-up coil in the exact moment that a neutron burst is formed in the center of the chopper, defining the zero time for the neutrons.

3. The chopper transmission function

The study of the chopper transmission for the IPEN instrument has been described elsewhere [4]. The chopper transmission, or the probability per unit time for the passage of a neutron through it, is a function, $T(t,v)$, of the neutron velocity and of the instant t the neutrons pass through the center of the chopper. The study as a function of time can be reduced to the study as a function of the angle of incidence α between the neutron path and the chopper slits in a rotating reference system connected to the chopper and with $t = 0$ coinciding with the crossing of the axis of rotation [3]. This theoretical development has been carried out in detail for the case of a chopper with a similar geometry to the one of IPEN [3,8]. The chopper transmission,

obtained by integrating the transmission function $T(\alpha,v)$ with respect to the angle α, is a function of the neutron wavelength λ and of the angular speed ω. The results are as follows:

$$T(\omega\lambda) = \begin{cases} \dfrac{d}{r}\left[1 - \dfrac{2}{3}\dfrac{r^4}{d^2}\dfrac{m^2}{h^2}(\omega\Delta\lambda)^2\right] \\ \qquad \text{for } 0 \leqslant \omega\Delta\lambda \leqslant \dfrac{d}{2r^2}\dfrac{h}{m}; \\ \dfrac{8}{3}\sqrt{2\dfrac{m}{h}d\omega\Delta\lambda} - 4\dfrac{m}{h}r\omega\Delta\lambda \\ \qquad + \dfrac{2}{3}\dfrac{m^2}{h^2}\dfrac{r^3}{d}(\omega\Delta\lambda)^2 \\ \qquad \text{for } \dfrac{h}{m}\dfrac{d}{2r^2} \leqslant \omega\Delta\lambda \leqslant \dfrac{h}{m}\dfrac{2d}{r^2}; \end{cases}$$

where h is Planck's constant and m is the mass of the neutron.

When the chopper is in the $0°$ position, $\Delta\lambda$ is given by:

$$\Delta\lambda = [\lambda - \lambda_0], \qquad \lambda_0 = \frac{h}{m}\frac{1}{2\omega R_0}.$$

A new burst of neutrons is emitted after the chopper has been rotated by $180°$. In this case the transmission is still given by the above expressions, but now $\Delta\lambda = [\lambda + \lambda_0]$.

As the chopper transmission is a function of the product $\omega\lambda$, it can thus be experimentally determined by fixing one of the two variables and studying the transmitted intensity as a function of the other variable. Using the diffracted beam provided by the mica crystal, with a certain neutron wavelength λ, the transmitted intensity as a function of ω was measured for the experimental determination of the chopper transmission function.

4. Experimental procedure and results

The time-of-flight spectrometer was positioned in the scattering angle of $35°$ and a mica crystal with dimensions of $10 \times 8 \times 0.05$ cm^3 and $d = 9.95$ Å, was located at the sample position of the spectrometer and oriented in order to obtain the diffracted monochromatic neutron beam with 6.0 Å at this angle. For this adjustment, the chopper was removed from its usual position and a cadmium slit was placed in front of the bank of ^{3}He detectors in such a way that only the two central detectors would be reached by the monochromatic beam emergent from the mica sample. In this arrangement a fine adjustment of the sample was performed to achieve the optimum diffracted neutron intensity. Then the cadmium slit was removed and the chopper was placed again in its position. A fission chamber detector was

located in front of the chopper for the monitoring of the neutron intensity.

After the procedures for the mica crystal orientation, the time-of-flight spectra for several chopper speeds were measured. Typical spectra for two given chopper speeds are shown in fig. 1, where for each ω two peaks with narrow Gaussian shapes are presented: the first one corresponding to the neutrons transmitted by the chopper in the 0° position and the second peak being related to the 180° chopper position. This can be verified by observing the coincidence of the time interval between the peaks with the half-period of chopper rotation, given by π/ω. In the time scale of fig. 1, the first peak appears in a position that corresponds to the time spent by the neutrons with 6.0 Å wavelength to go through the flight path of 3.15 m between the chopper and the detectors. The intensities of the peaks, normalized for the monitor counting, are proportional to

the transmission curve at the corresponding $\omega\lambda$ point.

Using the 6.0 Å neutron wavelength, chopper transmitted spectra were measured in the $\omega\lambda$ range between 1000 and 8300 Å rad/s. However, in order to confirm that the shape of the experimental transmission curve is invariant with a change of λ, another, similar experiment was performed with a neutron wavelength of 4.3 Å corresponding to the 25° scattering angle of the spectrometer. The experimental points corresponding to each of the experiments were normalized using only the maximum of each curve and, as can be seen in fig. 2, the remaining points became practically coincident in the whole overlapping range, showing that both curves obey the same $\omega\lambda$ function.

By fitting the equations of the transmission function with the experimental points, the numerical values for r/d and R_0 can be obtained. The full curves displayed in fig. 2 are the result of a least-squares fit made
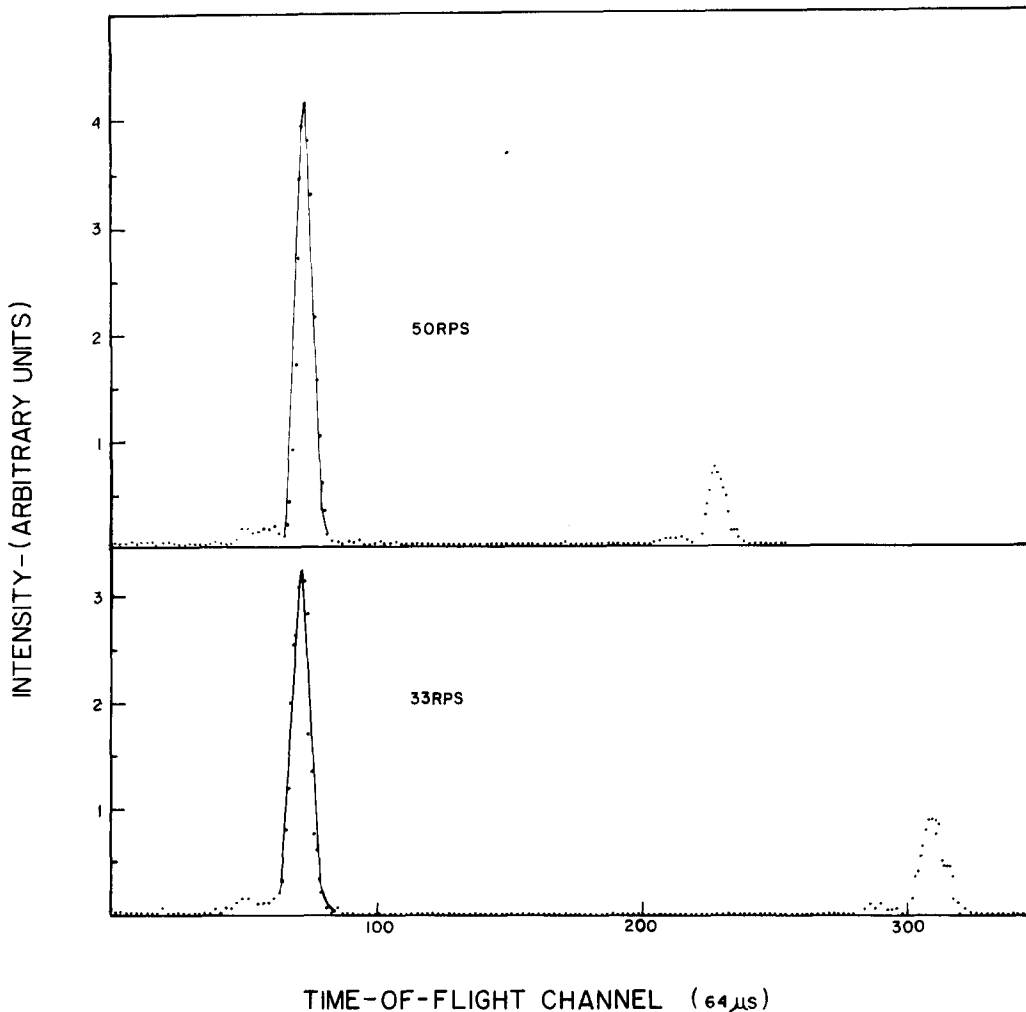

Fig. 1. Time-of-flight spectra of 6 Å neutrons for two different chopper speeds.
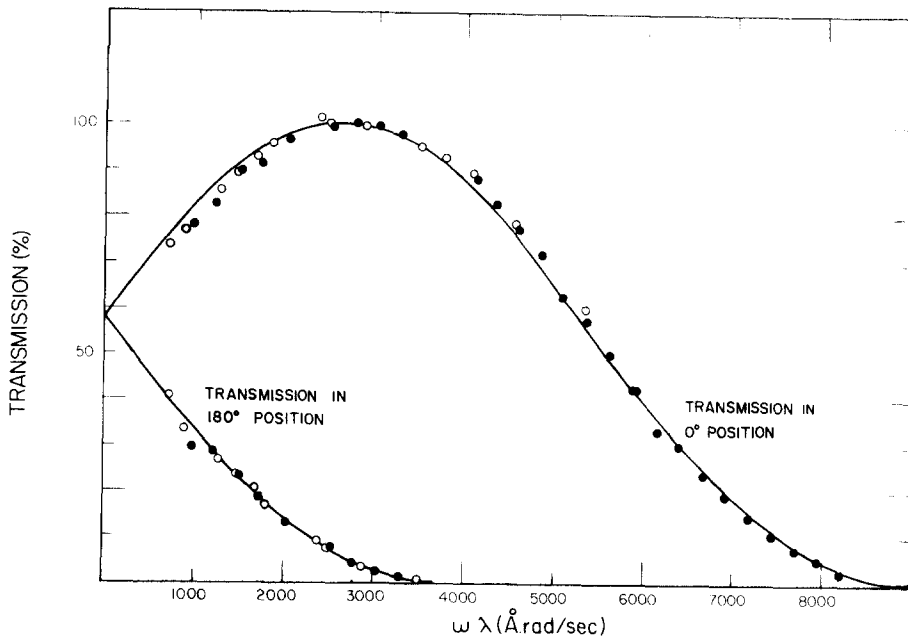
Fig. 2. Chopper transmission function: calculated curve and experimental points obtained by using 6.0 Å neutrons (full circles) and 4.3 Å neutrons (open circles).

simultaneously with the two parameters and also using at the same time the two branches, $0°$ and $180°$ transmission, of the curve. From the fit the following values were obtained: $r = 4.97 \pm 0.01$ cm and $R_0 = 74.8 \pm 0.3$ cm, taking the value 0.2 cm for d. Within the experimental errors, these parameters are in agreement with the nominal design values.

By using diffracted narrow beams provided by the mica crystal it was possible in the present work to obtain experimentally both the $0°$ and the $180°$ transmission curve, which were impossible to obtain in the previous work [2,3]. It was not necessary to perform several normalizations [3,4,9] to cover the whole $\omega\lambda$ interval, since in one run of experiments it was possible to measure the whole range of the transmission curve in both branches simultaneously.

In conclusion, this method that uses monoenergetic neutron beams can be considered as an alternative, simple and precise way of determining the chopper transmission function.

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