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A MECHANICAL NEUTRON FILTER FOR A CRYSTAL SPECTROMETER

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**NATIONAL REACTOR TESTING STATION
US ATOMIC ENERGY COMMISSION**

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SUMMARY

A velocity selector of the Dash-Sommers type with straight slits has been constructed for use with the MTR crystal spectrometer. The rotor is designed to remove undesirable higher order contaminants from the Bragg beam. Built of magnesium and fiberglass-epoxy laminate to minimize weight, it is driven directly by a 1/8-hp synchronous motor. The active length of the rotor is 21", the usable beam height 2". Vanes of fiberglass laminate are set into 235 slots milled around the periphery of a 4" diameter magnesium core. High strength is attained by winding the assembled rotor with glass filaments impregnated with epoxy resin. Effective helical pitch is obtained by setting the rotor axis at an angle to the Bragg beam. The rotor has been tested in the region below 0.25 ev. It is anticipated that the ultimate operating region will extend to 1 ev.

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A MECHANICAL NEUTRON FILTER FOR A CRYSTAL SPECTROMETER[†]

J. R. Smith and H. G. Miller

I. Introduction

The crystal spectrometer has long been one of the standard instruments used in low energy neutron research. Its utility resides in its ability to produce monochromatic neutron beams of high and constant intensity. In order for the Bragg beam to be truly monochromatic, it is essential that the components of the beam due to higher order reflections be eliminated. The helical slot velocity selector described by Dash and Sommers¹ is an especially attractive instrument for achieving this purpose, as it can be designed to give excellent order suppression, have high transmission, and operate over a wide energy region.

The operation of this type velocity selector is illustrated in Fig. 1, which is taken from the original article by Dash and Sommers. Only one of many longitudinal slots is shown. A neutron entering a slot will collide with the wall of the slot unless the wall is moving out of the neutron path at a rate that synchronizes with the motion of the neutron. The condition required for synchronization is

$$v = \frac{L\omega}{\phi_0},$$

where v is the velocity of the neutron, L the rotor length, ω the rotor angular velocity, and ϕ_0 the angle through which the slot advances along the length of the rotor due to its helical pitch. In practice the slot may be a true helix, or may be straight. In the latter case, the helix

[†]Work performed under the auspices of the U. S. Atomic Energy Commission.

is approximated by setting the rotor at an angle to the neutron beam. Rotors of both types have been built and operated successfully. Dash and Sommers¹ built one of the straight slot type for use as a monochromator, as did Efimov et al² and Senchenkov et al³ in Russia. Holt⁴ at Columbia University and Bally et al⁵ in Rumania have built helical slot rotors as mechanical neutron filters for crystal spectrometers.

II. Construction of Rotor

The straight slot rotor is considerably easier to build, and was chosen for construction at the Materials Testing Reactor (MTR) principally for this reason. It was felt desirable that the rotor should be capable of operating from the cold neutron region (≈ 0.001 ev) to energies in the neighborhood of 1 ev, with resolution adequate to isolate the first order neutrons from other orders in that range. Since it might be desirable in some experiments to remove the velocity selector, ease of handling was felt to be a necessity. For this reason, and to simplify the problem of driving the rotor at high speeds, an attempt was made to minimize weight. The Inelastic Scattering group at the MTR has had several years' experience in the operation of a rotor drive system⁶ using an audio oscillator to feed a pair of 200-watt amplifiers* driving a 1/8-hp synchronous motor.** It was hoped that a light enough rotor weight could be attained to make it possible to use the same drive system and thus benefit from experience already available in the Nuclear Physics Branch.

* McIntosh Model ML-200-AB, McIntosh Lab., Inc., Binghamton, New York.

** Type GH NRN/527, Electric Indicator Co., Stamford, Connecticut.

For construction of the walls of the rotor slots, a glass fabric-epoxy laminate was chosen. With the hydrogen in the epoxy resin and the boron in the glass, this material has about the same neutron-attenuating power in the region of interest as an equivalent thickness of nickel, with less than one-fourth the weight. A commercially available laminate 1/32" thick was used.* This was cut into strips 2-1/16" wide by 21" long. A total of 235 of these strips were set into slots milled 1/32" deep around the periphery of the 4"-diameter magnesium core. Magnesium was chosen as the core material because it is a light, strong material having better machining properties than does the reinforced plastic. Epoxy cement was used to cement the strips into the slots of the core. The core with about 80% of the vanes mounted is shown in Fig. 2. When all vanes had been cemented in, eight spacer rings of magnesium were slipped over the rotor as shown in Fig. 3. After the rings had been cemented in place, they were turned down on a lathe until about 3/32" of magnesium remained above the fiberglass. A winding of glass filament impregnated with epoxy resin** was next applied to a depth of 3/16" over the whole slot region of the rotor. This filament-wound shell gives the rotor the principal part of its radial strength.

After the rotor had been oven-cured to harden the resin in the winding, it was found to be somewhat out of balance. A precision balance was achieved by adding epoxy cement in amounts and locations indicated by a dynamic balancing machine. The completed rotor after balancing is shown in Fig. 4. The total weight of the rotor as

* Synthane Grade G-11 Synthane Corp., Oaks, Pennsylvania.

** 20 end/HTS Impregnated with E-710, U. S. Polymeric Chemicals, Santa Ana, California.

completed is 49 pounds. Figure 4 also shows the drive system for the rotor. On an integral extension of the rotor can be seen the motor armature, which had been removed from its original rotor and installed as shown. The motor windings were also removed from their original mounting and set into a water-cooled aluminum block mounted on one end plate of the rotor housing seen here. The motor case had to be replaced because it would have partially blocked the neutron beam. The top side of the new motor case was cut away, as were sections of the rotor housing end plates, to reduce neutron scattering.

The drive system shown proved to work very well indeed. Although the rotor has not yet been tested at very high speeds, its operation is very smooth between 1800 and 7500 rpm. It is anticipated that speeds as high as 12,000 rpm will be possible. Full amplifier power is used to start the rotor, but once attained, a constant 6000 rpm speed can be maintained at an output power of 15 watts per amplifier. Several features contribute to the smooth operation. In the first place, the all-in-one construction eliminates couplings and belts and requires only two small ball bearings. The entire motor-rotor combination runs in a vacuum to reduce air friction, and there is no problem of maintaining a vacuum seal around a shaft rotating at high speed. The overall length of the rotor housing is 28", which is not much greater than the length that would have been required to accommodate a pulley if the rotor had been belt-driven. Some saving in length was effected by recessing the bearings into the rotor core. The rotor axle consists of steel stubs mounted on the housing end plates and extending into the bearings. This arrangement also facilitates operation of the oil flow lubrication, which will be used at higher rotor

speeds. An oil slinger for this system can be seen projecting from the end of the rotor core in the photographs of the rotor. Thus far all running has been done with grease-packed bearings.

The assembled rotor system is shown in Fig. 5, mounted on the crystal spectrometer arm. The housing case is an aluminum cylinder with a half-inch wall thickness. This serves to align the ends, on which the axle stubs are mounted, enclose the rotor in a vacuum, and act as a safety shield. The end plates are made of one-inch aluminum. On the end visible in the photograph are the vacuum line nipple and the magnetic pickup. The latter monitors the speed of the rotor by transmitting pulses induced into it by two small steel screws threaded into one oil slinger. On the other housing end plate are connections for electrical power for the motor and cooling water for the motor coils. The combined weight of the rotor housing and motor is 65 pounds.

The whole assembly rides on a pair of aluminum angle sections. It pivots on a pin inserted into the spectrometer arm and into the rotor housing beneath the center of the rotor. Rotor offset is adjusted by means of a length of threaded rod mounted on one aluminum angle and threaded through a block attached to the spectrometer arm. The offset is measured with a micrometer attached to the angle and using the fixed block as an anvil.

III. Rotor Performance

As a first test of performance of the rotor in the neutron beam, the transmitted intensity was measured as the rotor offset was varied, first with the rotor stationary and then with the rotor at a constant speed of 6600 rpm. The two curves obtained using Be (10 $\bar{1}$ 1) monochromator at 0.025 ev first order energy are shown in Fig. 6. The

double peak in the curve obtained with the rotor spinning represents the separation of the first two orders of reflection. To confirm the order separation, the Bragg beam was analyzed by time-of-flight. A Fermi-type chopper was installed on the spectrometer arm ahead of the velocity selector. This chopper can be seen in Fig. 5. The time-of-flight spectra corresponding to the data of Fig. 6 are shown in Fig. 7. The top curve shows the Bragg beam components without the velocity selector in operation. The middle curve was obtained with the rotor spinning at 6600 rpm and offset to pass the first order neutrons and the bottom curve was obtained with the rotor offset to pass second order neutrons. In both of the latter cases elimination of unwanted orders appears to be complete.

At 0.25 ev the second order fraction is much lower than at 0.025 ev, but still could be a nuisance in some experiments. The time-of-flight spectra obtained with and without the velocity selector in operation are shown in Fig. 8. The performance at 0.25 ev with rotor speed 6000 rpm also provides an approximation to what the performance would be at 1 ev with a rotor speed of 12,000 rpm.

At the low end of the energy range, the unwanted orders may supply most of the Bragg beam. To check the rotor under these conditions, a mica crystal was used to provide a beam of 0.00167 ev first order energy ($7 \text{ \AA}$ wave length). Figure 9 shows the time-of-flight analyses of this Bragg beam with and without the rotor operating. Since the beam hole looks straight at the reactor core through a limited amount of moderator, the first order intensity is very low in this energy region. Nevertheless, the higher order neutrons are attenuated to such an extent that order discrimination is complete.

The final curve, Fig. 10, shows the total cross section of gold in the energy range 0.023 - 0.08 ev, as obtained with the crystal spectrometer using the velocity selector as a filter. Also shown are the data measured by the MTR fast chopper⁷ in the same energy range, using a different gold sample. The differences at the low end of the scale can be attributed to the fact that the two samples were prepared differently and have different microcrystalline structures. This discrepancy illustrates the problems involved in attempting to specify a standard sample or a standard cross section at a single energy. The small differences around 0.05 ev may also be due to the crystallinity effects, although they may also be due in part to small errors in dead time corrections. Aside from these areas the agreement between the two sets of data is excellent.

The only disappointing factor in the performance of the rotor is its transmission. While its intended transmission is 60%, its observed transmission is about 12%. This is due partially to the fact that problems encountered in milling the slots in the core led to an undesirable bending of the rotor vanes. Also a factor may be that the longitudinal divergence of the rotor slots, measured at mid-height, is less than that of the beam in which the transmission was measured. The rotor is thus acting as a collimator. Nevertheless, peak counting rates of 10^5 per sec. first order neutrons have been observed, and this is more than adequate for many experiments. To increase the filtered beam intensity further, a second rotor is being constructed, using the experience gained with the first rotor to prevent bending of the vanes. In order that the rotor may more closely match the divergence of the beam in which it is to be used, the number of vanes is being decreased from 235 to 150.

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Figure 1 - Schematic representation of helical slot velocity selector.

Figure 2 - MTR velocity selector rotor with fiberglas vanes partially in place.

Figure 3 - Rotor with all vanes mounted and spacer rings added.

Figure 4 - Completed rotor and motor drive unit.

Figure 5 - Velocity selector in its housing shown mounted on the crystal spectrometer arm for use as a mechanical neutron filter.

Figure 6 - Counting rate vs rotor offset. The monochromator is Be (10 $\bar{1}$ 1) at 0.025 ev first order energy. The square data points were obtained with the velocity selector stopped, while the round points were obtained at a rotor speed of 6600 rpm.

Figure 7 - Time-of-flight analysis of the Bragg beam from Be ($10\bar{1}1$) at 0.025 eV first order energy. The top curve shows the spectrum obtained without the velocity selector in operation. The middle curve was obtained with the velocity selector rotating at 6600 rpm and offset to pass only the first order neutrons. The bottom curve shows data obtained with the rotor offset to pass only second order neutrons.

Figure 8 - Time-of-flight analysis of the Bragg beam from Be ($10\bar{1}1$) at 0.25 eV. The top curve shows the beam composition without the rotor in operation. The bottom curve shows the spectrum obtained at 6000 rpm rotor speed with the rotor passing only first order neutrons.

Figure 9 - Time-of-flight spectrum of the Bragg beam from mica at 0.00167 eV first order energy ($7 \text{ \AA}$ wave length). The top curve shows the components present in the unfiltered beam. The bottom curve shows the composition when the velocity selector rotor is operating to pass only the first order neutrons.

Figure 10 - Total cross section ($\sigma\sqrt{E}$) of gold measured by the MTR crystal spectrometer and by the MTR fast chopper. The effects due to difference in microcrystalline structure are evident.

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