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GROOVED COLD MODERATOR AT KENS

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Summary

A grooved cold moderator was installed at the KENS target station which increased the cold neutron intensity by 1.4 compared with the flat one which had been operative without any trouble for more than two years and a half. The paper discusses the results of the mock-up experiment as well as a simulation calculation performed to find optimal parameters and reports the final design of the moderator. By employing the same refrigerator (PGH-105), the moderator could be cooled down to 20.5 K under the operation of maximum proton current. The neutron energy and time spectra from the grooved moderator as well as the heat deposit in the moderator by nuclear radiation were measured to compare with the results obtained for the flat one. A recent chemical analysis of radiation decomposition of solid methane in the old flat moderator suggests that the decomposition is about three times faster than the previous case reported in ICANS-IV.

Introduction

The KENS first cold moderator made by solid methane with a dimension of 5 x 12 x 15 cm^3 (flat moderator)[1),2)] had been operative without any trouble for more than two years and a half, and had proved a satisfactory performance for its high coupling efficiency and effective cooling ability. Many experiments with the KENS cold neutron source have also demonstrated that the spallation neutron source has a good potential for cold neutron scattering works.

With an increase of population in this research field, however, the requirements for the machine time and for increasing the cold neutron intensity became much strong, which made us investigate the possibility of replacing the old moderator by a grooved one to improve the situation. A promising aspect of the grooved moderator was discussed by Bauer[3)] and Carpenter[4)] in ICANS-IV (KEK) and it attracted the attention of many neutron people, because the moderator was shown to improve substantially the intensity of the slow neutrons. Many mock-up experiments reported in ICANS-IV - VI have shown that the improvement by the grooved moderator would be a factor of 1.2, if the moderator is embeded in a good reflector and the comparison is made for the moderator with an equal volume[5)-9)]. The gain factor depends strongly on the condition of the reflector[10)]. Recent mock-up experiments using Hokkaido University LINAC as well as a simulation calculation have suggested that the grooved moderator with optimal parameters would increase the present cold neutron intensity at KENS by about 50 %. We therefore decided to replace the flat moderator by the grooved one and the replacement was completed at the end of March 1983. The paper discusses first the results of the simulation calculation and mock-up test, and describes the actual design and performance of the new moderator. Note that the replacement is the first step of the KENS-I' project.

Simulation calculation

A simulation calculation was made for a simple model system to find the optimal parameters. The model used for the calculation was of polyethylene at ambient temperature without reflector. The calculation was made by using a two dimensional SN transport code TWOTRAN-II[11)]. Then the geometries of grooved and flat moderators under consideration are the infinitely long columns, the sections of which are shown in Fig. 1, both having the same volume. The nine group neutron cross sections were calculated by the SRAC code[12)].

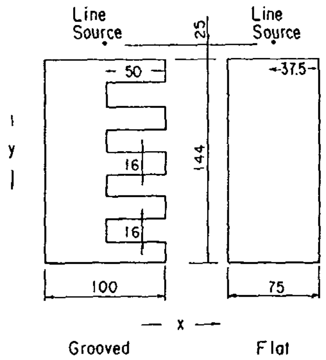

Fig. 1 Two-Dimensional Model for Reference Moderators

As a demonstration shown in Fig. 2 are the spatial distributions along y-direction of the beam currents of the eighth energy group (0.04 ∿ 0.01 eV) from the grooved and the flat moderators. Both curves are normalized by the unit line source. We can see the sharp shoots of beam currents appearing from the bottom of grooves. The results are in good agreement with those obtained in a previous test experiment[9)].

The mechanism of the increase of neutron beam currents from the grooved surface is discussed in detail in the original paper[13)]. Here we refer to the ratio of the first flight collision in the grooved moderator to that in the flat one with the same volume, G/F = 1.15 obtained by this simulation calculation. This ratio, η = G/F is important for comparing the heat deposit in two moderators.

The parameter survey was performed for position of target, overall dimension of moderator (thickness and height) and geometry of grooves (depth of groove, pitch of groove-fin and ratio of groove width to fin's). The results for the important parameters are summarized below.

1) The position of target in the x direction (cf. Fig. 1) has small influence on the neutron gain.

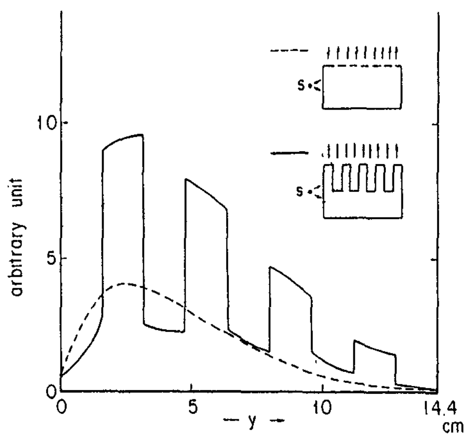

Fig. 2 Y-Dependence of Beam Currents (8th Group) from the Reference Moderators

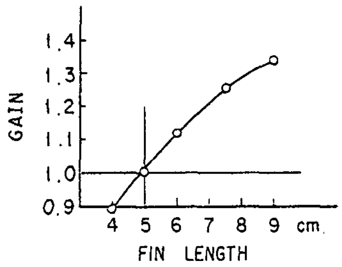

Fig. 3 Effect of Fin Length on Beam Current

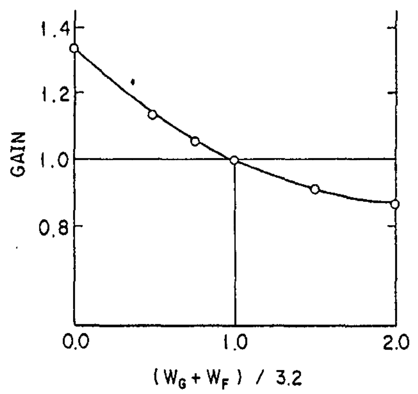

Fig. 4 Effect of Groove Pitch on Beam Current

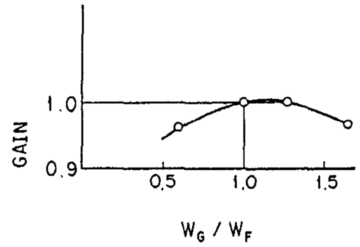

Fig. 5 Effect of Ratio of Groove Width to Fin Width on Beam Current

2) The extension of the thickness of the moderator in the backward direction beyond 5 cm increases the intensity by 10 % for 1 cm extension.
3) The extension of the height beyond 14 cm does not effect the neutron gain as is found in Fig. 2.
4) The extension of the fin length has a significant effect on the gain (12 % gain/cm), which is illustrated in Fig. 3. We can find there is still 6 % of gain per cm beyond 3 cm extension.
5) The effect of pitch, the sum of groove and fin widths, was surveyed by changing the pitch upon keeping both widths equal and total height unchanged. The result shown in Fig. 4 indicates that the more narrow pitch yields the more gain.
6) The ratio of groove width to fin's was surveyed by changing the ratio upon keeping the pitch 3.2 cm. As shown in Fig. 5, it seems that the optimum ratio is between 1.0 and 1.25.

Mock-up experiments

The mock-up test experiments for surveying the design parameters were carried out at the Hokkaido University LINAC neutron source by employing the polyethylene moderator at ambient temperature which was embeded inside a graphite reflector with a similar shape to the upper part of the KENS reflector. The energy spectra of neutrons from a 15 x 15 x 5 cm^3 flat moderator and a 15 x 15 x 10 cm^3 grooved one with 5 cm depth grooves are compared in Fig. 6, which shows that the intensity gain by the grooved moderator is about 1.4 at the peak of energy spectrum and it becomes higher for longer wave lengths. If referred to the flat moderator with the same volume, the intensity gain is anticipated to be 1.3 at the spectrum peak. For the parameter survey, the effect of depth of grooves was examined under the condition of the constant volume.

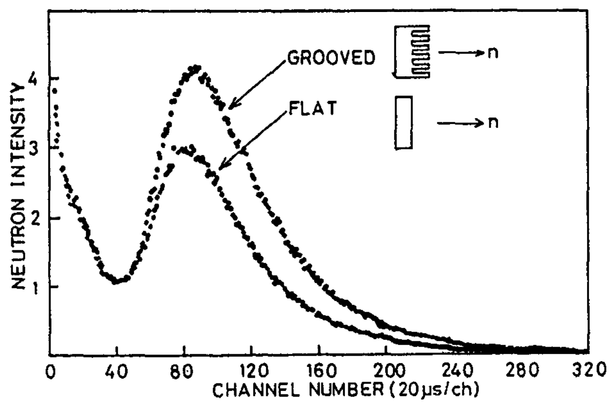

Fig. 6 Time-of-flight Spectra from Grooved and Flat Moderators

The total moderator thickness was limited to be 10 cm because of spatial allowance in the KENS Be reflector. The results are displayed in Fig. 7, which suggests that the maximum intensity is obtained for the maximum fin's length of 5 cm. The result agrees satisfactorily with the simulation calculation. In Fig. 8 are also shown the neutron intensities from the grooved moderators with various height of the lowest fins. The neutron intensity was found not so sensitive to this height in a range of 10 ∿ 20 mm.

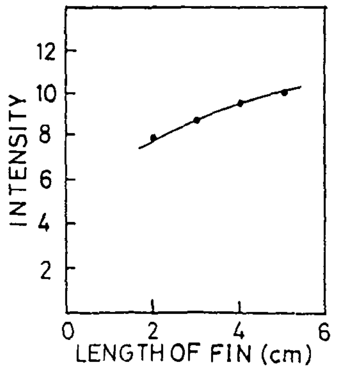

Fig. 7 Effect of Length of Fins

Design and fabrication of KENS grooved cold moderator

Figure 9 is the side view of the grooved moderator we finally fabricated with its photograph. The overall dimension of the new moderator, the ratio of grooved width to fin's (1.28), number of fins, depth of grooves and height of the lowest fin are determined based on the results of mock-up test experiment and simulation calculations described in previous two sections. The methane container is made by pure Aℓ, the wall of fins is only 2 mm thick, while other parts of the container have the thickness of either 4 or 5 mm. The container is cooled by the same method as the previous one with some improvement. The total volume of methane is 1,544 cc which is an increase of 70 % of volume compared with the previous one. The reservoir tank for methane gas was also replaced to a new bigger one (0.8 m^3) corresponding to the volume change of the container. Several small pieces of Be reflector were also fabricated to fill up the vacancy between the new moderator cryostat and the main unchanged Be reflector.

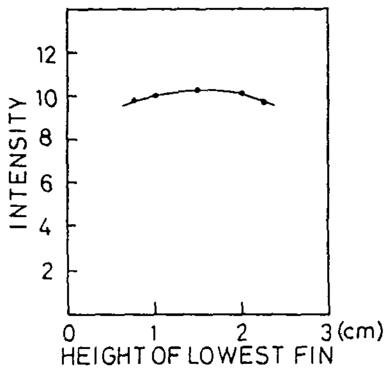

Fig. 8 Effect of Height of the Lowest Fin

Performance of the new moderator

The energy spectra at the exit of the neutron guide tube from the new grooved and old flat moderators were measured by the neutron scattering from a standard vanadium sample. Their intensities were normalized by measuring epithermal neutron current from an ambient temperature moderator located at the opposite side of the target. An appreciable change was found in the energy spectra as seen in Fig. 10. The ratio of the intensity of cold neutrons from the grooved moderator I_g to that from flat one I_f was found to be wave length dependent. The ratio is 1.4 $\sim$ 1.5 in the wave length range 5 $\sim$ 8 A which is important for the spectrometers with neutron guide tubes (SAN, TOP and LAM-80), while the value is only 1.2 at the Maxwellian peak of the cold spectrum (λ = 4 A). (Note that the energy spectra shown in Fig. 10 are modified by the transmittance of the neutron guide tube and are different from the real one.) The values are less than those anticipated from the mock-up tests, presumably due to the better reflector system for KENS.

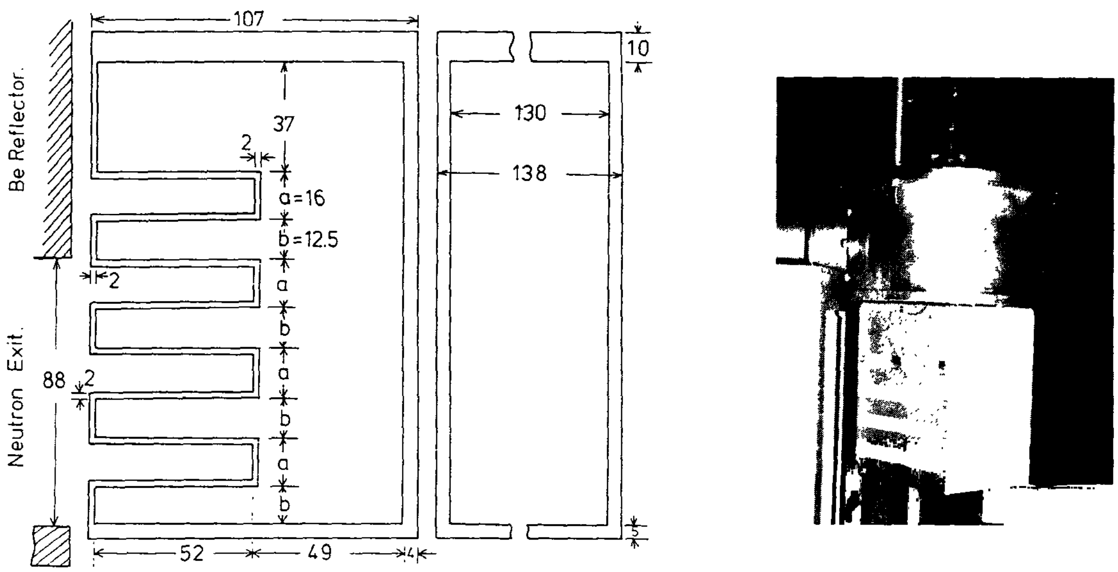

Fig. 9 The Side View of Grooved Moderator and its Photograph

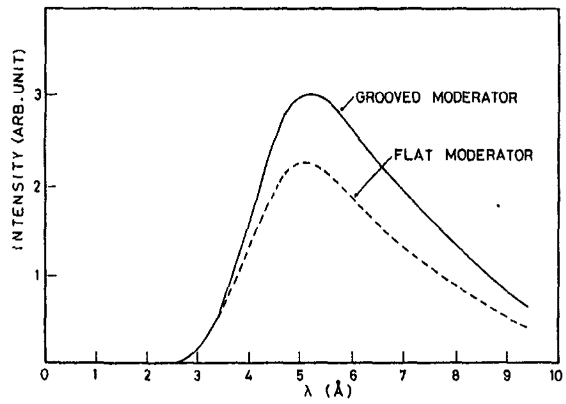

Fig. 10 Energy Spectra of Grooved and Flat Moderators

The time spectra of cold neutrons were measured by back scattering from a mica single crystal and are displayed in Fig. 11. The spectra have a time-structure in the rising part, which becomes substantial for longer wave lengths. However, it is confirmed that the structure gives no serious problem to the profile analysis for the quasi-elastic spectrometer LAM-40 which utilizes 4 A neutrons. This was turned out to be also the case for the high resolution quasi-elastic spectrometer LAM-80 even if it employs the neutrons of 6.6 A.

The result of cooling performance with and without proton beams are displayed in Fig. 12. Without the proton beams, the methane could be cooled down to 16.8 K, the lowest temperature that our refrigerator (PGH 105) can attain. The temperature of methane was found to rise up to 20 K by full proton currents 1.5 μA). The result in Fig. 12 was obtained with the proton currents of 1.0 μA to get an accurate temperature rise. The amount of heat q deposited in the moderator by nuclear radiation could be estimated from the temperature rising curve in Fig. 12 as was done in the previous paper[2]. The temperature rise $\Delta T(t)$ is given by

$$\Delta T(t) = g(1 - e^{-ht}) ,$$

with $g = q/K$ and $h = K/C$, K and C being thermal conductance and heat capacity of the moderator respectively. By employing the parameters g and h determined from Fig. 12, q was estimated to be $q = ghC = 4.9$ watt.

The total heat deposit thus estimated is almost four times larger than that in the old moderator as is compared in Table 1. If the total deposit is normalized by the proton current, the total volume of the moderator and the ratio of the first flight collision rate $\eta = G/F = 1.15$ obtained by calculation, the normalized heat deposit becomes 1.9 times larger than the flat case (Feb. 1983). It is not clear whether such a discrepancy is due to the real change of situations or is simply due to the accuracy of the approximate calculation for q. Note that the normalized heat deposit estimated for the flat moderator at the end of its use (Feb. 1983) is 1.3 times higher than that measured at the beginning (Jul. 1980).

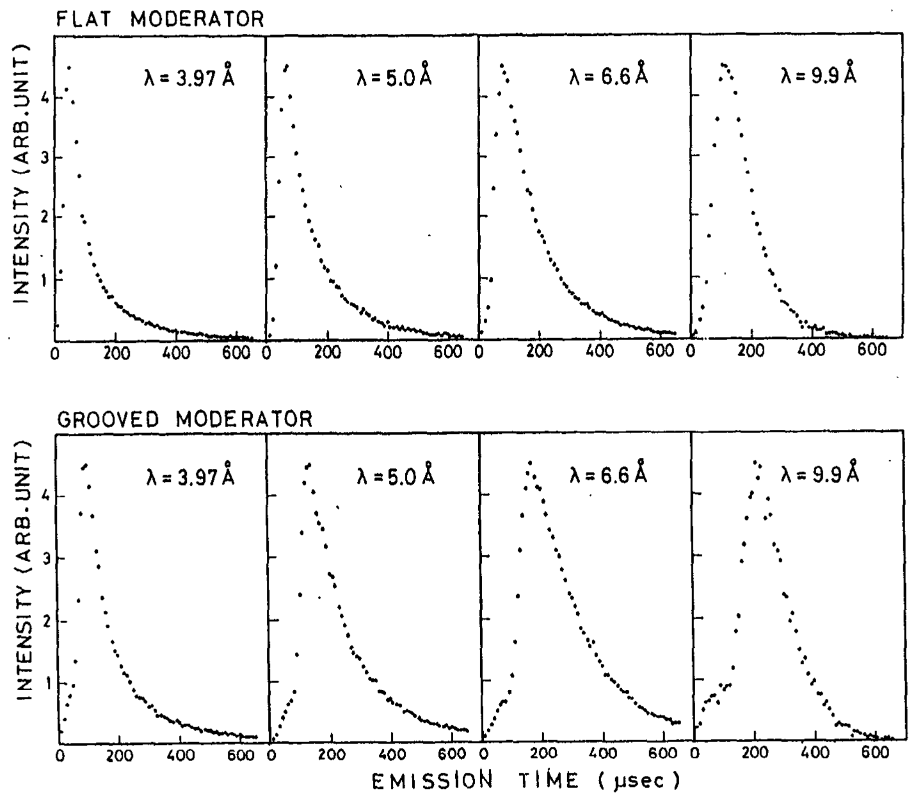

Fig. 11 Time Spectra of Grooved and Flat Moderators

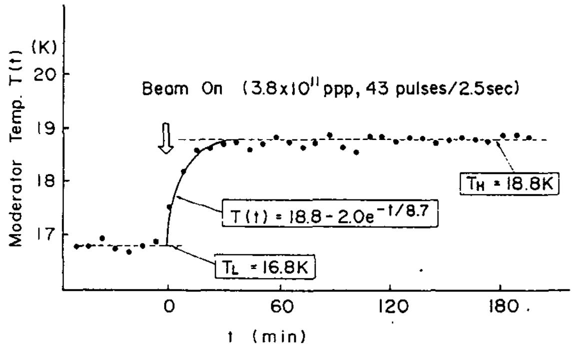

Fig. 12 Temperature Rise of Grooved Moderator by Nuclear Radiation

Table 1 Heat Deposit in Cold Moderators by Nuclear Radiation

	Flat Moderator (Jul. 1980)	Flat Moderator (Feb. 1983)	Grooved Moderator (Jul. 1983)
Proton Intensity (current I, μA)	7.3×10^{12} protons/sec (1.2)	8.0×10^{12} protons/sec (1.3)	6.5×10^{12} protons/sec (1.0)
Volume V (cm^3)	900	900	1,544
Bottom Area S (cm^2)	60	60	131
Temperature Rise (K)	1.0	1.4	2.0
Thermal Conductance K(J/K·sec)	1.08	1.09	2.46
Total Heat Deposit q(W)	1.2	1.7	4.9
Normalized Heat Deposit (= q/VηI) ($mW/cm^3 \cdot \mu A$)	1.11	1.44	2.75

Table 2 Product Yields Due to the Radiation Decomposition of Solid CH_4 Moderator

	H_2 (%)	CH_4 (%)	C_2H_6 (%)	C_2H_4 (%)	Other (%)	H_2 Production Rate (%/10^{18} protons)
Sample A (Feb. '83)	0.81	98.8	0.15	0.2	0.1	0.30
Sample B (Mar. '83)	0.35	99.5	0.1	<0.1	<0.1	0.26
Sample C (Jul. '80)	0.15	∿100	0.03	0.06	0.03	0.11

Irradiation condition

	Proton Current (μA)	Irradiation Time (hours)	Total Protons (x 10^{18})
Sample A	1.40	87.0	2.74
Sample B	1.47	40.9	1.35
Sample C	1.2	52.7	1.42

Radiation decomposition of solid methane

The chemical analysis of radiation decomposition products in the exhausted gas was carried out for the methane gas used for the flat moderator. The analysis for the grooved moderator is in progress. The sample gases A and B to be assayed were taken from the reservoir tank, and the total number of 500 MeV protons on the W target were 2.74×10^{18} for the sample A and 1.35×10^{18} for the sample B, respectively. The chemical analysis was performed by gaschromatography. The concentrations of individual products (listed in Table 2) were calculated from the peak area in the gas-chromatograms and sensitivity of each gas to the detector. The results were listed in Table 2, together with the total number of protons for each sample. The results obtained in an earlier measurement are also listed for reference. As far as the present results are concerned, a linear relation holds between the H_2 product and the total number of protons on the W target. However, the H_2 production rate is three times larger in the recent measurement than the previous one. At present we have no explanation for the discrepancy, but we suspect that the recent increase of production rate would be related with the increase of the heat deposit. Further investigation is required before we get a confirmative conclusion.

It should be noted that the replacement gave us an opportunity for examining the inside of the old cold moderator container to find the deposits created during the 2.5 years operation. This would give us an important information on the decomposition process of solid methane by spallation neutrons. This examination will be carried out as soon as the radiation level of the cold moderator container reduces to the accessible one.

Conclusion

The KENS grooved cold moderator has also been operative since April 1983 with a satisfactory performance. The change of the time spectra has practically no influence on the present spectrometers. The increase of the cold neutron intensity from the guide tubes by 40 ∿ 50 % is quite invaluable. The total cost for realization of this increase is about ¥16.5 x 10^6 including the expenses for the mock-up tests and for the modification of the Be reflector.

We should also remark that the increase of 40 % of the cold neutrons by the new grooved moderator is partly due to the increase of the moderator volume. Therefore, our result obtained with a real good reflector target system gives an experimental support to the expectation that the net gain by grooving is of order of 1.2 in case of the good reflecting system and the gain is significant only in a long wave region.

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