# Multistage UCN Turbine and Replica Supermirror for Very Low Energy Neutron Generation and Transportation

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Abstract

The extraction of VCN and the generation of UCN is important for having very low energy neutrons at the experimental facilities. The trial fabrication of replica supermirrors for VCN guide tubes and the new concept of the mechanical neutron decelerator for UCN generation using multilayer monchromators are reported. As for the VCN extraction, the neutron guide tube must be inserted closely to CNS. So it must be tough against irradiation and heat cycle. Replica Ni-Ti supermirrors are developing to enhance the VCN extraction efficiency. The multistage neutron turbine using multilayer monochromator is also proposed as a new mechanical neutron decelerator. As the incident neutron angle to the reflection blade is perpendicular, it enables to let neutron go straight through three stages. Though the incident velocity is about 150m/s, the velocity change in one stage is much smaller than the Doppler shifter. It makes monochromators much easier to be fabricated. The deceleration efficiency with the monochromator reflectivity of unity in this three stage turbine is about 0.47 from 150m/s to UCN(5 - 7 m/s), and that of the final stage is about 0.6 from 50m/s to UCN.

## 1. Introduction

One of the frontiers of research reactor utilization is the very low energy neutron physics. The trend of neutron beam experiment is shifting to the lower energy. Though the current main demands are thermal and cold neutrons, very cold neutrons (VCN) and ultracold neutrons (UCN) will be much more important. The number of VCN-UCN user will increase rapidly, when the intense low energy neutron sources are improved. To serve such very low energy neutrons, the extraction of VCN and the generation of UCN are discussed.

Most of neutron mirrors in the guide tubes are Ni deposited on glasses and they are not so strong against the irradiation damage. The beam divergence of thermal and cold neutrons is small. Thermal and cold guide tubes don't need to be inserted deeply, nevertheless the guide tube units close to the reactor core sometimes must be changed. It is impossible to use the same type of neutron mirrors for the VCN extraction, because the VCN guide tube must be set very close to CNS cell. It will suffer a severe irradiation. Neutron mirrors enduring a hard environment are essential for VCN guide tube. The replica Ni-mirror guide was developed by Garching group and installed in the vertical guide tube of PF2, ILL[1]. It showed that the effectiveness of the close approach of guide tube to CNS and that replica mirror works well in the severest environment. As supermirrors are more effective because of its wide Q reflection range, replica supermirrors are required for the better extraction efficiency,

The UCN generation ways are classified into 3 types. The first one is the direct extraction from CNS[2]. It is sometimes difficult to meet safety regulation because it don't allow thick windows for UCN extraction. The second one is the superthermal method using liquid Helium-4 [3]. This is suitable for some special purposes, for example EDM measurement, but it also has a difficulty to extracting UCN from the cryogenic cell to outside. The third one is the combination of CNS and the mechanical neutron decelerator. This method gives a good general purpose UCN source. The combination of CNS and Streyerl turbine in ILL[1] is one of the most intense UCN source in the world. The neutron turbine for the continuous neutron source and the Doppler shifter [4,5] for the pulse source are practically used. The design works of neutron turbine for ANS[6] and that of multilayer Doppler shifter for LPSS[7] are performed for the higher UCN flux. A new concept of mechanical neutron decelerator, which is a multistage neutron turbine[8], and the first result of the trial replica supermirror production are described in this paper.

## 2. Multistage neutron turbine for UCN generation

### 2.1 Concept of multistage turbine

The existing neutron turbines, which are Steyerl turbines in ILL[1] and FRM[9], and a supermirror turbine in KUR[10], are used in research reactors as the continuous neutron sources. Neutrons are decelerated by series of reflections on a blade. The centrifugal and Coriolis' forces cause the complicated changes of the neutron trajectories during the neutron deceleration. It makes the efficiency worse. So the slower feed neutron velocity is suitable for the better deceleration efficiency because of the slower rotational speed of the rotor. However, the extraction efficiency of slower neutron from CNS to the turbine becomes worse because of the transmission loss through the CNS containment walls.

On the other hand, the Doppler shifter is used in an accelerator as a pulse neutron source. It reflects a neutron only once on a crystal or a multilayer monochromator to decelerate. As the Doppler shifter has one blade for one neutron pulse, it has an upper limit of the effective incident time width. When the setting position of the shifter is too far from the target or the inlet neutron velocity is too slow, the deceleration efficiency becomes worse because of the wide spread of the incident neutron time structure. As for the monochromator fabrication, the large velocity change of the neutron velocity in the deceleration demands the high performance of the mirror blade. It is not so easy to prepare such good reflectors.

The multistage type decelerator in this paper has no such limitation written above. The total system is shown in Fig. 1. The feed neutrons go into the rotor at the angle of 45°. As they are reflected perpendicularly on the surface of the blade, neutrons go straightly through three stages of the turbine. It enables to use faster feed neutrons. The first stage changes the neutron velocity from 150m/s to 100m/s. The initial velocity is as fast as the Doppler shifter. The second and third stages change it from 100m/s to 50 and 50 to UCN, respectively. The velocity deceleration in the third stage is similar to those of the Steyerl and supermirror turbines. The main parameters are shown in Table 1. The performance of the multilayer monochromator demanded is much easier than that of the Doppler shifter. The installation precision of the feed guide tube and the turbine is also easier than the other systems because of the reflection angle of 90°.

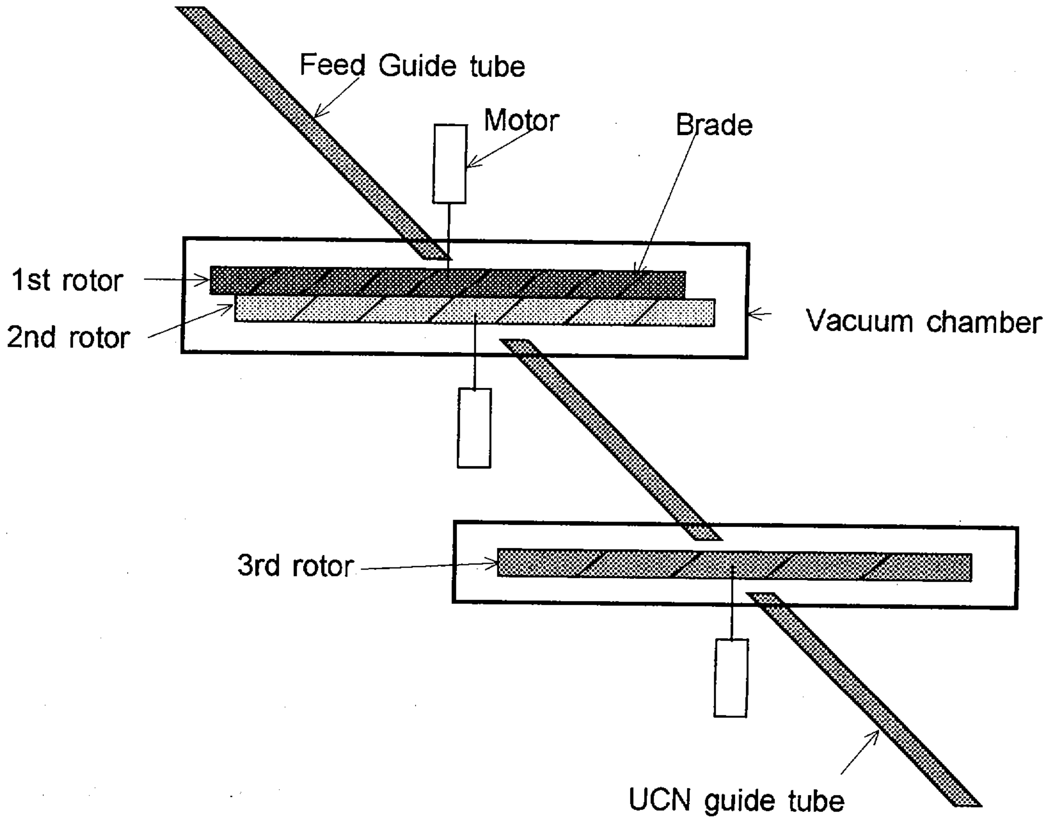


Fig.1 Plan view of multistage neutron turbine

Table 1 Main parameters of the multistage turbine

| | 1st stage | 2nd stage | 3rd stage |
|---|---|---|---|
| rotor radius (cm) | 200 - 50 | 200 - 50 | 100 - 30 |
| rotor width (cm) | 2 | 2 | 2 |
| revolutions (rps) | 10 (R=200cm) | 6 (R=200cm) | 9.5 (R=100cm) |
| pitch of blade (cm) | 1.1 | 1.4 | 6.8 |
| velocity change (m/s) | 150 → 100 | 100 → 50 | 50 → UCN |
| monochromator | | | |
| center velocity | 25m/s (160A) | 25m/s (160A) | 20m/s (200A) |
| resolutions (half width) | 20% | 20% | 25% |

2.2 Calculated performance

As the feed guide tube will be a natural nickel guide, the neutron velocity components perpendicular to the guide tube axis are less than 6m/s in this calculation. The beam width is wide enough to feed full illumination to the inlet of the blade, and it is 6cmW by 6cmH. The angle between the incident neutron beam and the moving direction of the reflecting blade is 45°. The angle of the reflection mirror to the moving direction is also 45°. So the feed neutron beam is reflected perpendicularly on the mirror surface of the blade, and it goes straight with spreading the beam divergence. Neutrons are not only decelerated but also accelerated by the blade with the reflectivity of unity.

Neutron trajectories are calculated by Monte Carlo method. As the source spectrum is defined as the Maxwell spectrum, the neutron density is constant in the velocity phase space. The deceleration efficiency is defined by the ratio of the UCN density to the original incident density. The calculated deceleration efficiencies in each stages are shown in Fig.2-5. The deceleration efficiency in this three stage turbine is about 0.47 for the decelerated velocity of 5 - 7 m/s from 150m/s and that of the final stage is about 0.6 from 50m/s with the monochromator reflectivity of unity. They decrease to 0.34 and 0.54 when the monochromator reflectivity becomes 0.9.

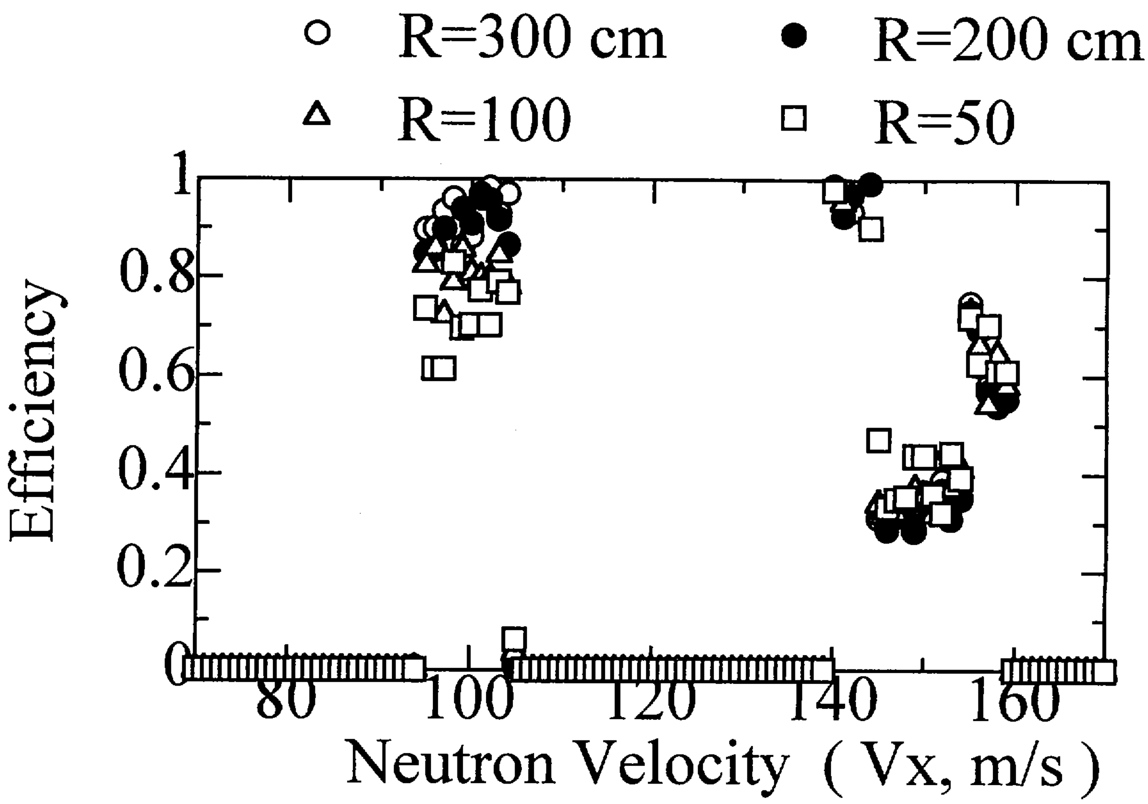


Fig.2 Deceleration efficiency in the first stage ( 150m/s → 100m/s )

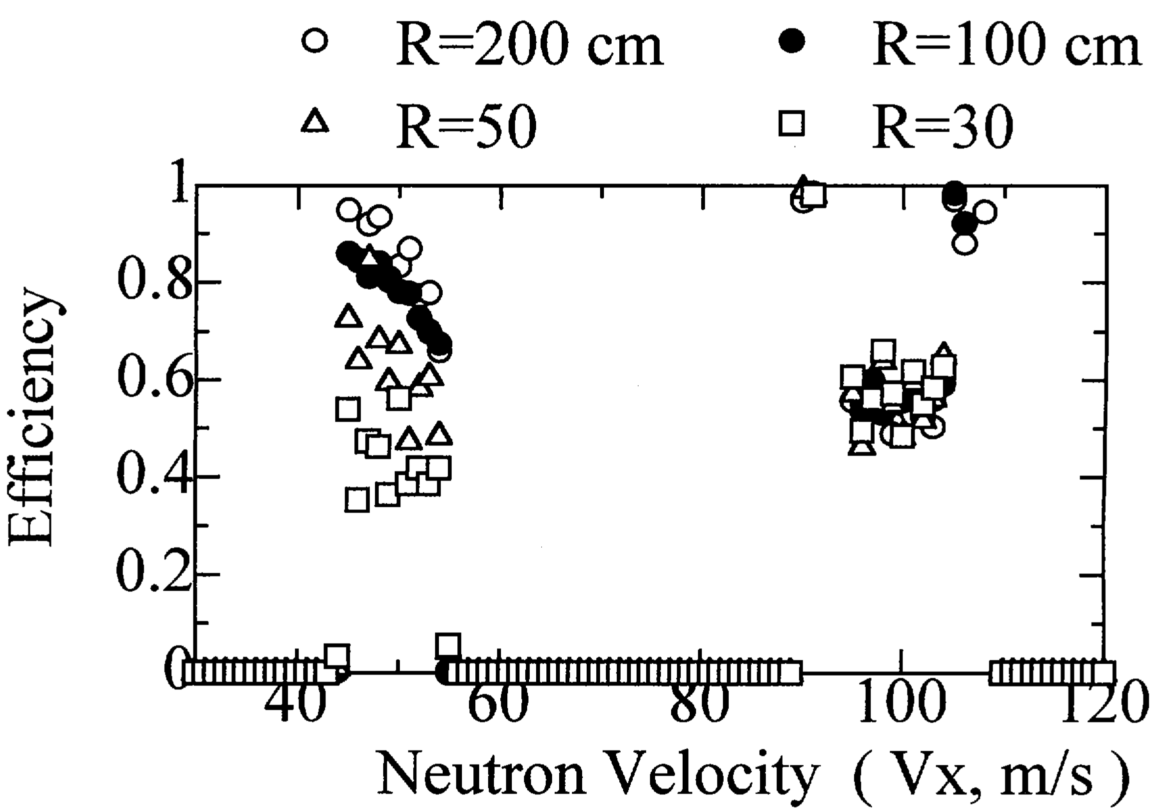


Fig.3 Deceleration efficiency in the second stage ( 100m/s → 50m/s )

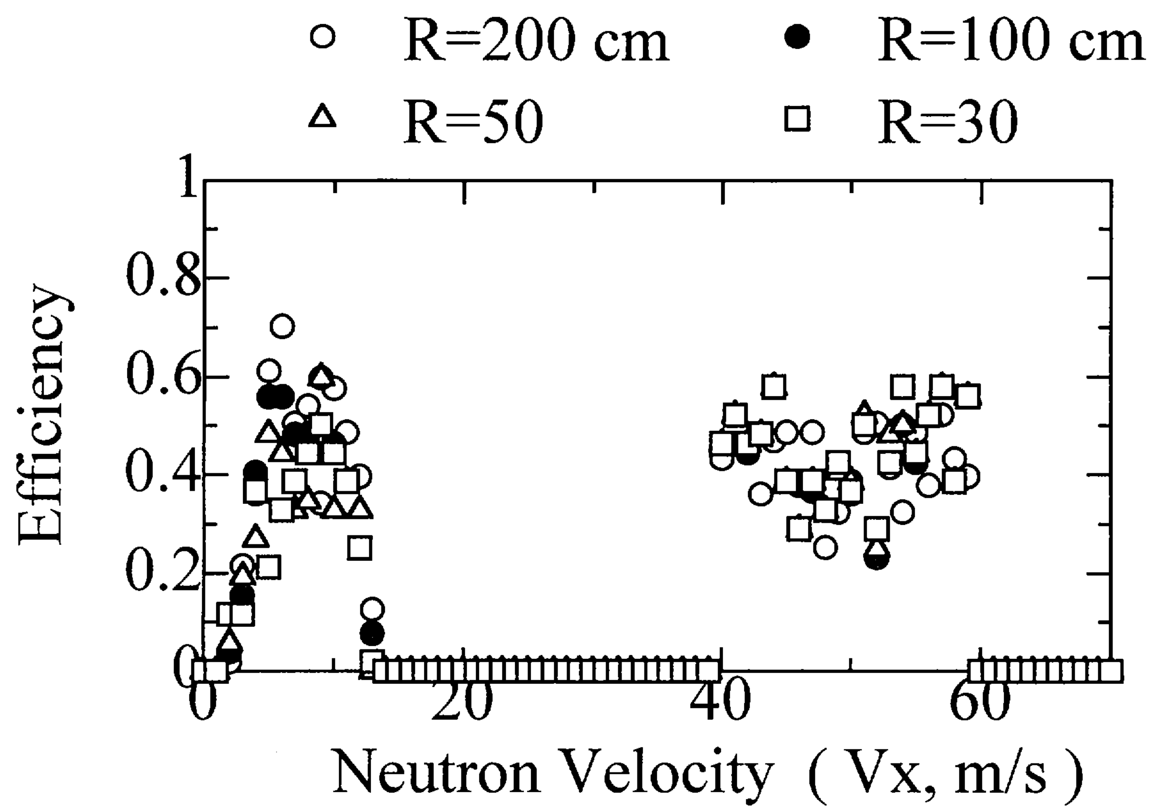


Fig.4 Deceleration efficiency in the third stage ( 50m/s → UCN )

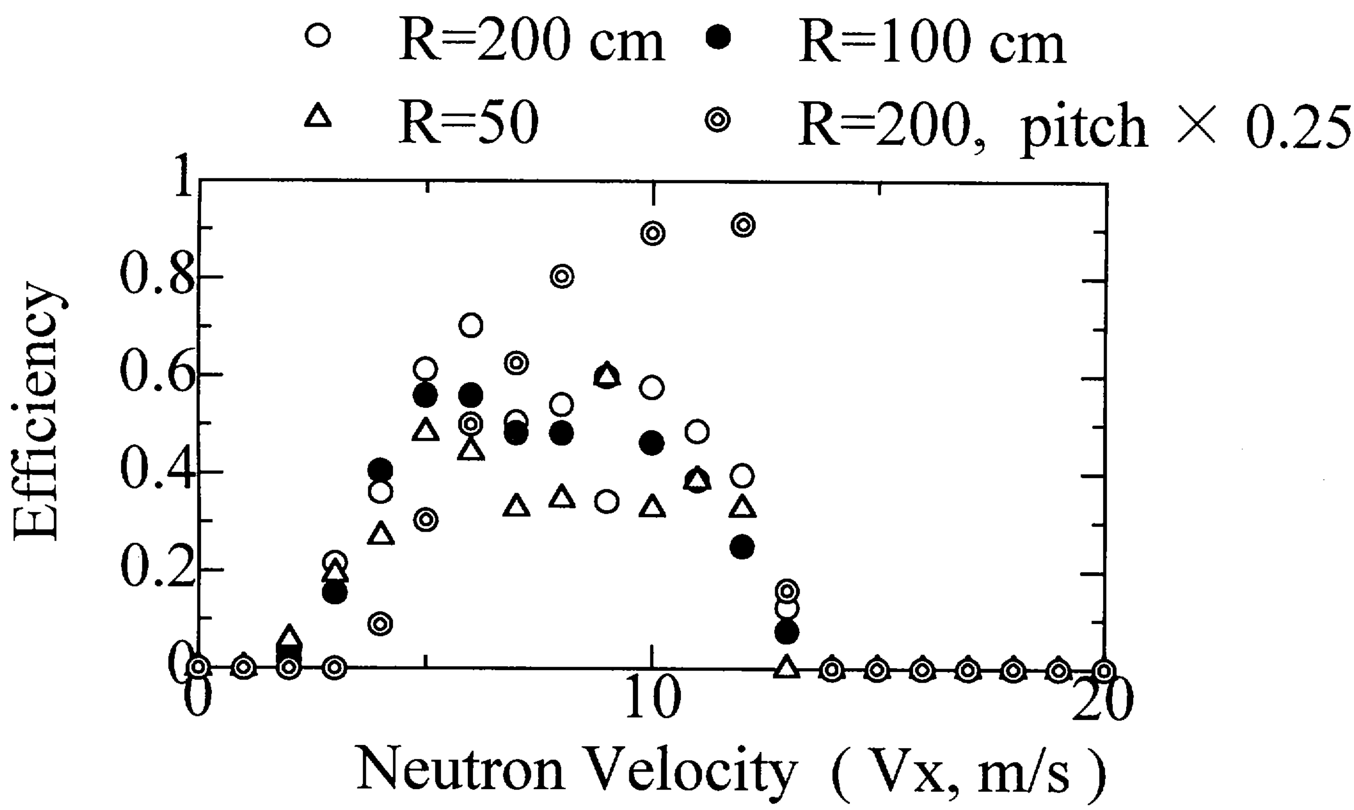


Fig.5 Deceleration efficiency in the third stage ( 0 - 20m/s )

3. Replica supermirror for VCN extraction

To enhance the extraction efficiency of VCN, replica supermirrors are developing. They are Ni-Ti multilayers and Cu is electroplated. Supermirrors are deposited on glass plates by the vacuum evaporation method in KURRI supermirror fabrication facility. After copper is electroplated on supermirrors, they are removed from a glass plate. It makes a metal supported replica supermirror.

Reflectivity is measured at the cold neutron TOF measurement system of the cold neutron guide port, CN2-3, JRR-3M. The incident cold neutron beam divergence is collimated to be 1.4 x $10^{-3}$ rad. The flight path length is 1320 mm. The collimator width of the chopper is 1mm and revolution is 3000rpm. The reflectivity of the replica supermirror is shown in Fig.6. The reflectivity of the replica supermirror is almost same with that of the supermirror on the glass plate and also similar to the design value which is calculated from the evaporated layer thickness. The measured reflectivity shows the possibility to realize a good replica supermirror. The roughness of replica mirrors measured optically is Ra= 1.3 - 2.0 nm and it is almost as good as the glass plate. The flatness is not so good, usually. It makes the reflectivity worse because of the spread of the reflection angle. The replica mirror easily waves because of thin thickness. Here, the

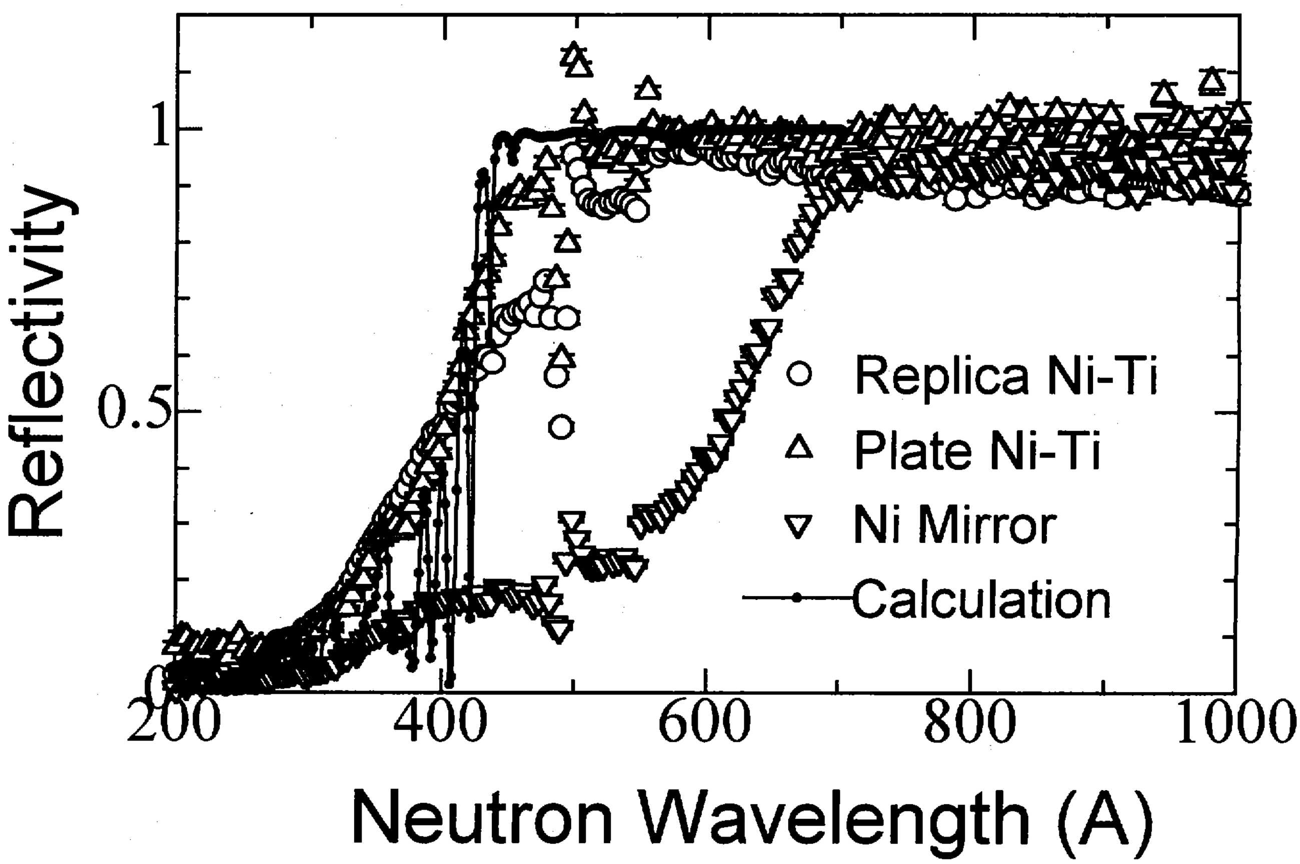


Fig.6 Reflectivity of replica supermirror

replica supermirror is fixed by the medical polymer which is used for fixing the artificial tooth. The beam divergence from the replica mirror is shown in Fig.7. The beam divergence changes to about 7 x $10^{-3}$ rad after the reflection. It shows the flatness of the replica mirror is kept about 3 x $10^{-3}$ rad during the measurement. It is possible to hold it flat for the practical use.

The Q range of the replica supermirror reported in this paper is designed to be not so good because this is the test piece to confirm the fabrication method. As the supermirror fabrication facility in KUR has a large experience to make supermirrors by the evaporation method, it is easy to enhance it to 2Q. As for the thickness of Cu plating, It can changes from 4 $\mu$ m up to 0.3mm. When it is 0.3mm thick, it is strong enough to make a guide tube. The minimum thickness suggests us the possibility of stacking several mirrors to enhance the Q range.

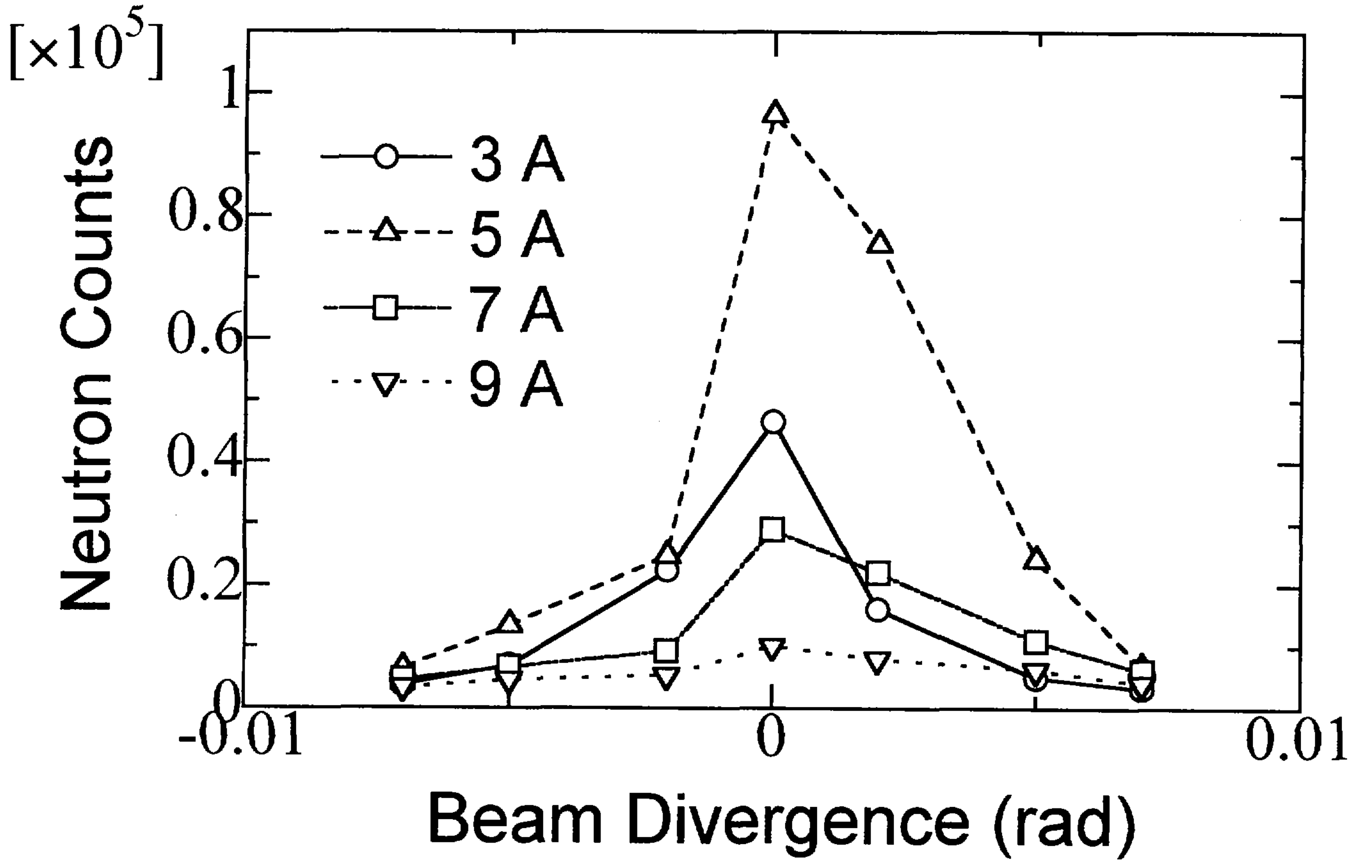


Fig. 7 Reflected beam divergence from the replica supermirror

4. Concluding remarks

As the new techniques of the very low energy neutron generation and transportation, the concept of the multistage neutron turbine and the development of the replica supermirrors has been described in this paper.

The multistage turbine using multilayer monochromator has three stages to decelerate neutrons. Neutrons are reflected only once in each stage. The incident neutron velocity is about 150m/s. The incident angle of neutrons is 90° to the reflection mirror which enable to let neutron go straightly. This arrangement of multilayer monochromator makes it possible to lessen the neutron reflection number than neutron turbines. The straight configuration enables to make multistage deceleration. The velocity change in one stage is much smaller than the Doppler shifter. It makes much easier to fabricate monochromators. The multistage turbine has a possibility of higher deceleration efficiency than the existing neutron turbines and the Doppler shifters.

It is also demonstrated that a replica supermirror can be fabricated. The Ni-Ti supermirror is evaporated and Cu is electroplated as the base material. The reflectivity of the replica supermirror is almost same with the design value which is calculated from the evaporated layer thickness. The measured reflectivity shows the possibility to realize a good replica supermirror for the practical use.

From the point of view of the very low energy neutron utilization, there are many stages from the reactor source to the experimental equipments. The final neutron flux for utilization is the results of the performances of all of these stages. The neutron transportation and deceleration are as important as the reactor flux. The demands of developing this middle stage, the neutron transportation and tailoring technique, is growing for supplying the very low energy neutrons.

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