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Design of High Efficiency Supermirror Neutron Turbine

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The supermirror neutron turbine which decelerates very cold neutrons (VCN) to ultracold neutrons (UCN) in the VCN-UCN facility installed in Kyoto Univ. Reactor (KUR) was upgraded with the use of an improved version of polygonal blades made of five supermirrors, in place of the previous three supermirror blades. Since the main reason of the neutron loss is complicated changes of the decelerated neutron trajectories in the turbine rotation, a second step upgrading is performed with the use of a multisections VCN feed guide in a converging type which changes the VCN beam feeding position and direction according to the inlet position and height in the rotating mirror blades in order to cancel the centrifugal force effects. Further, in order to minimize the effect of the Coriolis force, the mirror blades of the turbine are made smaller to diminish the size ratio between the blades and the turbine rotor radius.

KEYWORDS: supermirror neutron turbine, ultracold neutron source, VCN feed bender

§.1. Introduction

A VCN-UCN facility has been developed at Kyoto Univ. Research Reactor (KUR) which is 5MW light water cooled and moderated. The whole system of the very low energy neutron facilities consists of a cold neutron source (CNS) [1], a VCN guide tube [2], a VCN bender [3], a supermirror neutron turbine [4,5] and UCN experimental equipments.
The turbine system was selected in KUR to be efficient and advantageous for the use as a multipurpose UCN source. The present research fields in KUR using UCN are improvements of the supermirror turbine [6], a neutron bottle for neutron decay measurements [7], developments of UCN detectors [8], magnetic confinement of UCN [9], UCN polarization [10], gravity spectrometer [11] and deceleration of UCN by a magnetic field[12].

§.2. Structure of supermirror turbine

The CNS facility has four beam lines as shown in Fig.1. Three among them are for cold neutrons with a collimated direct beam, a nickel guide and a supermirror guide, respectively. The fourth one is prepared for VCN and UCN. The structure of the supermirror neutron turbine is shown in Fig.2. The design velocity for the feed VCN is about 50m/s, and the turbine biades move in the direction of VCN incident flow with the velocity of about 25m/s, reflect VCN, and decelerate them to UCN. The diameter of the turbine rotor is 1m. The upgraded blade is constructed with five flat supermirrors, the structure of which is shown in Fig.3, while the old blades consisted of three mirrors. The present improvement gave a better polygonal mirror arrangement and a gain factor for the UCN intensity of about 3 was obtained.

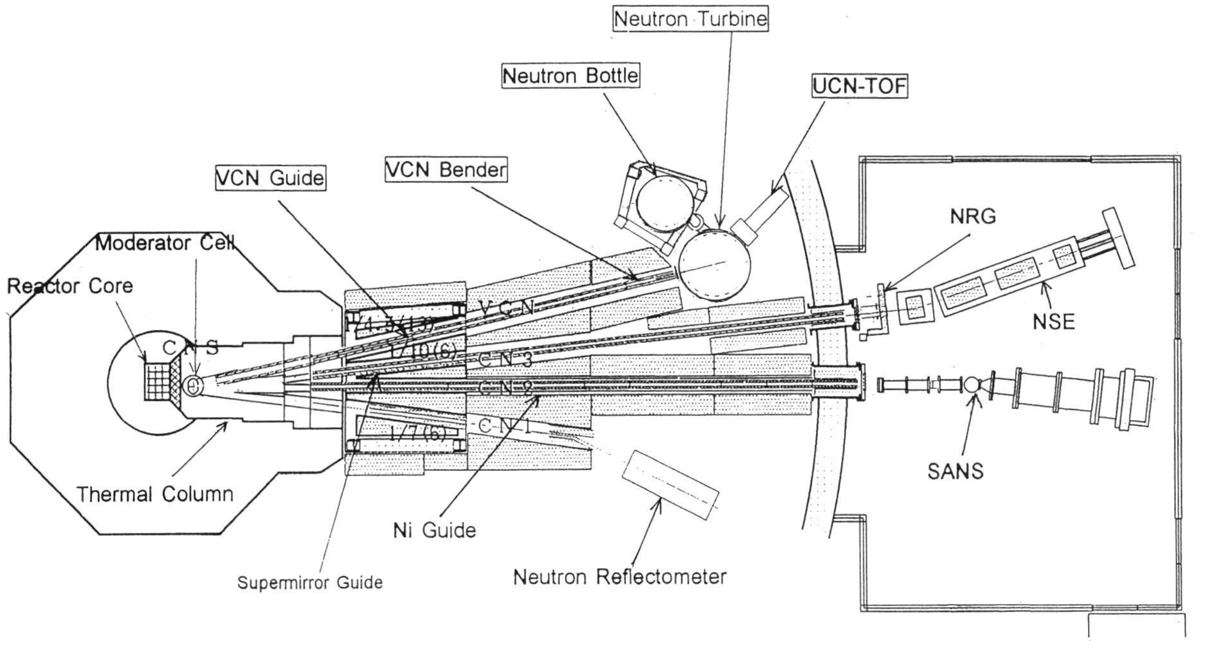

Fig.1 Arrangement of the very cold and ultracold neutron facilities.

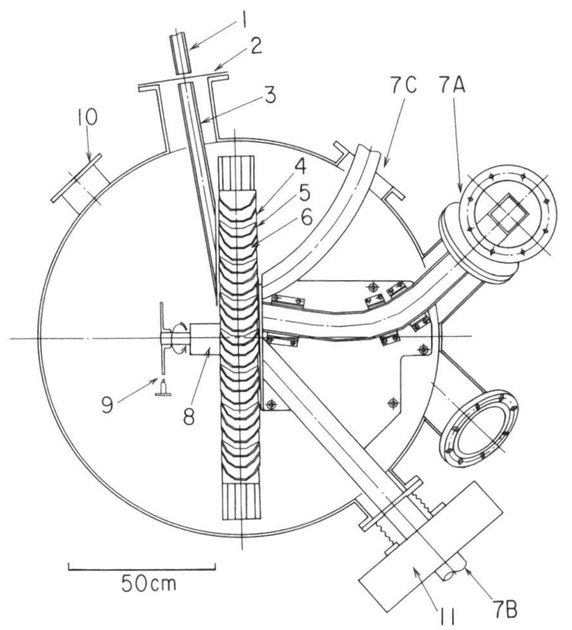

Fig.2 Structure of supermirror neutron turbine,

1:VCN bender, 2:Aluminum window, 3:VCN feed guide, 4:Turbine rotor, 5:Supermirror blades, 6:Lower reflecting mirrors, 7A:UCN port for bottle experiments, 7B:UCN port for time-of-flight experiments, 7C:UCN port for neutron optics experiments, 8:Turbine shaft, 9:Rotation pickup, 10:Evacuation port, 11:UCN chopper.

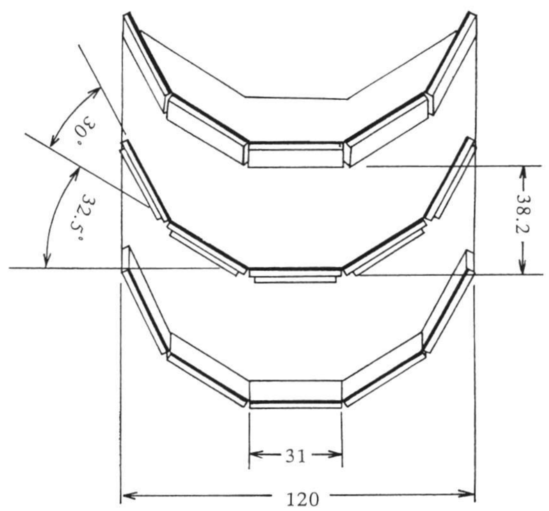

Fig.3 Structure of upgraded 5-mirror blades.

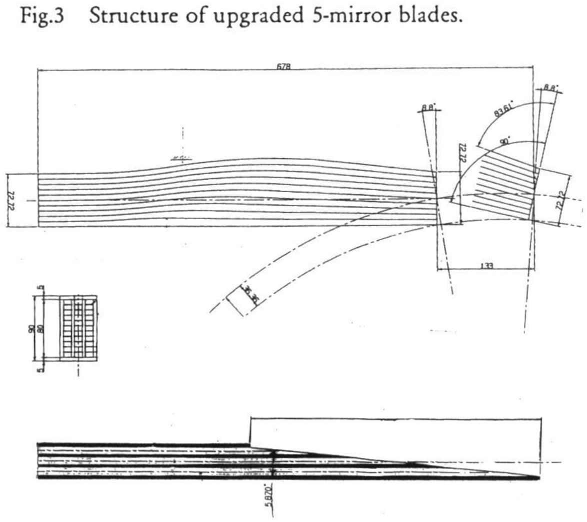

Fig.4 Structure of multisections VCN feed bender.

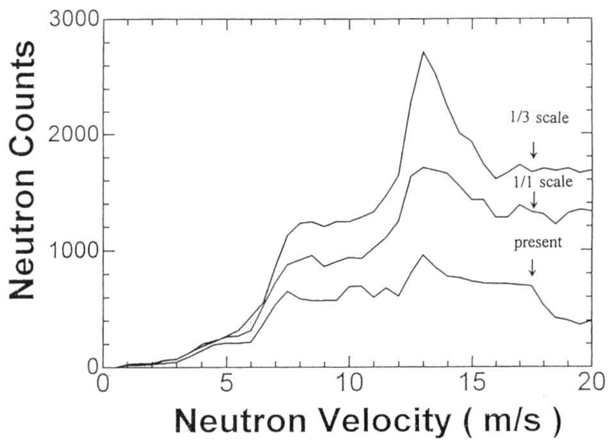

Fig.5 Effects of 1/3 miniaturization and high Q supermirror.

The VCN guide used at present is a simple straight guide of nickel mirrors shaped to feed VCN to the turbine blade with a small gap. The cross-section of feed guide is 35mm wide by 90mm high. The feeding width to turbine blades is 32.2cm because the glancing angle is as small as 6.6 degrees. It is wide enough but the angular condition of feeding direction is not suitable for the change of the angle by the rotation. The guide is also declined 8.8 degrees downward to compensate the centrifugal force effects.

§.3. Multisections VCN feed bender

The main neutron loss factor in the blade is the complicated changes of the decelerated neutron trajectories affected by the centrifugal force and Coriolis' force. Therefore, we designed a VCN feed bender which converges the VCN beam to cancel the centrifugal force for every VCN trajectory.

The inlet direction of a section in the feed VCN beam is decided by the horizontal glancing angle to the mirror blades and the vertical angle necessary to compensate the centrifugal force. The horizontal direction is decided using the velocity phase diagram under the assumption of straight movement of the blade. As for the vertical angle, it changes according to the peripheral position where the blade accepts feed VCN, because of the rotational motion of the blade. It must also be changed according to the vertical position in the blades, that is, the beam must be convergent. The feed VCN guide used at present is a straight nickel guide tube and it provides VCN for the wide area with a constant angle which is only suitable in the center position.

The structure of the new VCN feeder consists of combined three benders, as shown in Fig.4, which are correctly arranged respectively to the position of the rotating blade. Each bender is adjusted to compensate the effects of the centrifugal force.

§.4. Scale effect of turbine blade

In order to minimize the effect by Coriolis force, a new small mirror blade of the turbine is designed to diminish the size ratio between the blades and the turbine rotor. The size effect is estimated using a computer simulation. The revolution speed of the rotor studied is 5.0 ～ 7.5 rps. The inlet VCN spectrum is assumed to be Maxwellian. The geometry of the VCN feed is the present arrangement using a straight natural nickel guide.

Some examples of the calculated results are shown in Fig.5, where the revolution of the rotor is 5.0rps. The label 'present' shows the present blade size with the supermirror of 2.2 Q_{Ni}. The blade size of the others are 1/1 and 1/3 of the present one, where the supermirror used is 3.0 Q_{Ni}. The size effect of the blades is mainly observed in the region between 5m/s and 25m/s, which suggests a further analysis with a more detailed geometry is needed for the modification optimized for neutron velocities below about 5 m/s. The results of various size changes indicated that the size reduction to 1/3 is enough in these studies.

As the Maxwellian spectrum is used in these calculations, the effect of spectrum deformation should be considered in the practical designs. The real spectrum from the CNS is strongly deformed by the aluminum wall of the moderator cell. The slower neutrons are preferentially eliminated from the feed VCN. A faster rotor revolution is desirable from this point of view, but it enhances the effects of the centrifugal and Coriolis forces. Therefore, a partial set of miniature blades with the size 1/3 are prepared and performance tests will be carried out for studying the balance of these effects, which should be considered for the practical turbine design.

§.5. Concluding remarks

For improving the efficiency of the supermirror neutron turbine, the designs of the feed VCN bender and of miniature blades were proposed. The VCN feed bender is a combined triple bender correctly adjusted to the position of the rotating blade. Each bender is also bent so as to compensate the difference of the centrifugal force effects according to the inlet height to the blade. To minimize the effect by Coriolis force, the new mirror blade of the turbine is designed in a miniature version to diminish the size ratio between the blades and the turbine rotor. A sample of the miniature blades for studying the size effects is now in preparation and the performance will be tested in the near future.

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