JP0150562

JAERI-Conf 2001-002

ICANS-XV
15^{th} Meeting of the International Collaboration on Advanced Neutron Sources
November 6-9, 2000 Tsukuba, Japan

14.6
A large angle cold neutron bender using sequential garland reflections for pulsed neutron source

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Abstract

We discuss a basic structure and performance of a new cold neutron bender using sequential garland reflections, in order to bend a neutron beam with large divergence by large angle. Using this bender for a pulsed neutron source we could not only avoid the frame overlap for cold neutrons but also install a plural spectrometers at a cold guide and obtain polarized neutron beams if necessary.

1 Introduction

Neutron guide tubes and sequential garland reflection methods have been used for cold neutron benders. We have developed cold neutron benders using sequential garland reflections [1, 2, 3]. Using magnetic multilayer monochromaters, a simple garland reflection bender brings us a neutron beam which is monochromatized, collimated, polarized and bent. Benders of this type have been utilized for installing a several spectrometers at cold guide tubes of the KUR and JRR3 reactors. Double garland reflection benders are used for a spin echo and a small angle scattering equipment at cold neutron guides in order to monochromatize, collimate and polarize (for the former) their neutron beams simultaneously [4, 5]. A well-collimated monochromatized neutron beam with wavelength of 12.6 A and its resolution of 3.5 %(FWHM) is taken out bending by 24 degrees using a quadruple garland reflection bender at the C312 beam port of the JRR3 reactor [6]. This cold neutron beam is used for neutron optics and spin interferometry. A double garland reflection bender supplies a monochromatized cold neutron beam for the spin echo equipment installed at the C23 beam port of the JRR3 reactor [7]. It should be noted that the neutron yield through the benders mentioned above decreases with larger divergence of the beam, although they are adequate for large angle bending compared with a neutron guide.

We propose here a new garland bender in order to bend a cold neutrons with large divergence by a large angle in a short distance. This bender adopts a new idea relating to the mirror arrangement, in which reflected neutrons are focussed into the center position of the next mirror system. This mechanism reduces neutron loss through the bender caused owing to their large divergence. We have installed a bender of this type to obtain three cold neutron beam ports from the C312 port [8].

Utilizing cold neutron beams in a pulsed source, there is a serious problem of the frame overlap which short wave length neutrons catch up with long wave neutrons of the former pulse. It is one of the best way to separate in space the neutron beam into a shorter and a longer neutron wavelength components, in order to avoid the frame overlap without decreasing the neutron utility. Hence, it is very important for us to develop the beam bender which can reduce the neutron loss through the bender as well as bent neutron beam by large angle.

In this paper, we describe the principle and structure of the new bender, and its performance based on the simulations. Applicability of the new bender to a pulsed source and its usefulness are discussed.

2 Method of garland beam bender

The basic structure and performance of a garland bender are illustrated by garland reflections as indicated in Fig. 1 [1, 2, 3]. The designed reflection angle, θ, of the incident neutron is taken near the critical angle of the mirror and the neighboring mirrors are set with the twice angle, 2θ, of the designed reflection angle. A neutron beam is reflected by the designed angle on the average and bent by the twice angle of the reflection. Thus we can obtain an adequate bender when we have multiple reflections to attain the bent angle required for installing a spectrometer.

Neutron components incident parallel to the designed angle on the bender is hardly lost by multiple reflections. On the other hand, for a neutron beam with large divergence the neutron components which can not be incident on the next mirror, increase depending on the divergence, as shown in Fig. 1(a). These effects are more severe for the neutrons reflected in the edge part of the mirror than those in the center part. These neutron loss give rise to each reflection stage. Consequently a beam bender of this type should be improved for bending a large divergent neutron beam by large angle.

We consider an mirror arrangement in parabolic shape, which has the focussing point at the center of the next mirror, as shown in Fig.1(b). Then even neutrons incident on the both edge side are reflected into the center part of the next mirror. Consequently, we could increase neutrons which is incident on the next mirror for even a beam component with large divergence and reduce neutron loss by the bender. It, however, is not easy to arrange mirror system in a parabolic shape precisely. It is practical to approximate a parabola by three straight lines. In this paper, we evaluate the neutron characteristics of benders approximated a parabola by three straight mirrors, which consist of a center part and two same edge parts bent by a same angle to the center part, as shown in Fig. 1(c). The yield probability of neutron obtained through the bender is simulated by a ray tracing method. Supermirrors are used for reflection mirrors. Then the wavelength range of the neutrons obtained through the bender depends on the design angle, 2θ, between the two neighboring mirror assemblies. We define the shortest wavelength, λ_b, of them as

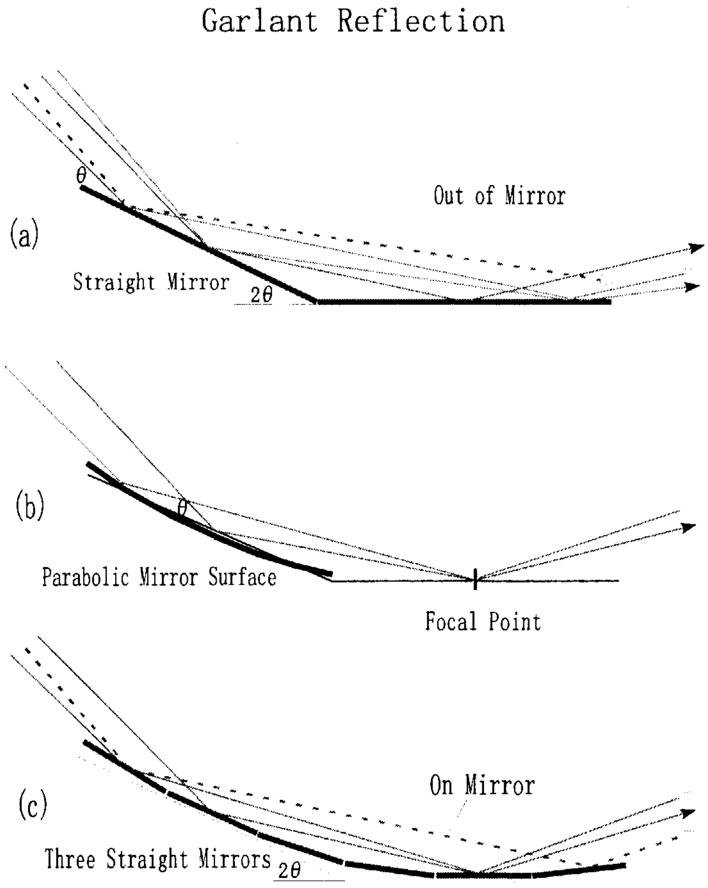

Figure 1: Structure and principle of garland reflection bender;(a) garlend reflections by straight mirrors, (b) garlend reflections by parabolic mirror surface, which focuses the reflected neutrons at the center of the next mirror stage, (c) a new garland bender with assemblies of three straight mirrors, which approximate parabolic shape.

the characteristics wavelength of the bender, which is evaluated,

$$\lambda_b = \lambda_m \theta \tag{1}$$

where θ is the designed reflection angle, λ_m the critical wavelength of the supermirror.

We discuss typical bender conditions required for beam bending of 15 degree assuming beam width of 10 mm. Two channel beam bender is required for a beam with the width of 20 mm. The typical parameters of the bender and evaluated results are summarized in Table 1. Tangle is the total bent angle. Q is the Q number of the supermirrors and two cases of 2.25 and 3.0 were evaluated in this table. Dangle, 2θ, is the angle between the nearest neighbor mirror assemblies and is equal to the averaged neutron bending angle every reflection. Nrefl and Tlength are the reflection number and total length of the bender, respectively. Nyld is the neutron yield of the bender and normalized by the neutron intensity with divergence of half of the nickel total reflection angle. λ_{eb} is the effective characteristics wavelength of the bender, which gives the maximun neutron yield.

The simulated neutron spectrum through the bender is given in Fig.2, assuming 3Q

Table 1: Typical parameters of new garland benders, assuming the beam width=10 mm and the reflectivity of the supermirror of 95 %.

Tangle deg.	Q	Dangle deg.	Nrefl	Ulength cm	Tlength cm	λ_b Å	λ_{eb} Å	Nyld %
15	2.25	3.75	4	30.5	122.0	8.5	10.4	71
15	3.0	5.0	3	22.9	68.7	8.5	10.4	71

supermirrors with reflectivity of 95 %. The peak of the spectrum is at wavelength of 1.2 times longer than the characteristics wavelength and the spectrum profile reduces in longer wavelength side owing to the deviation from the designed reflection angle.

An assembly of mirror system consists of three reflection mirrors of the center part and a pair of symmetrical edge parts. The best values of the length of each part and the bending angle of the edge parts to the center part are determined by the parameter survey in the simulations. The best values are 0.38, 0.24 and 0.38 for the ratio of the partial length, and the bending angle of the edge parts is 1/8 of the designed reflection angle θ. The largest neutron yield indicated in Fig.2 is given by these best values.

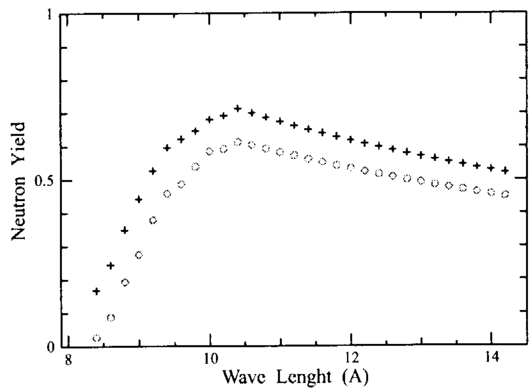

Figure 2: Evaluated neutron spectrum obtaining through new garland bender.

Generally remarking, when the reflectivity of supermirror falls, the neutron yield of the bender decreases considerably, especially, for the case required many reflections. For example, the neutron intensity decrease to 0.41 by four times reflections of mirror with reflectivity of 80 %. On the other hand, supermirror with high reflectivity of 95 % keeps high neutron intensity of 0.81 for the same reflection numbers.

The decrement of the neutron yield owing to a low reflectivity of the mirror is more serious for neutron guide tube, since neutron guide tube requires about twice reflections compared with the garland bender to obtain the same bending angle. The reflection angle of a neutron guide distributes uniformly from 0 degree to the critical angle. Thus the average reflection angle of guide tube is about half that of the garland bender. Anyway, for case of large bent angle we should use supermirrors with high reflectivity of 95 %

and high Q value of more than 3. Otherwise, the large loss of neutron due to the low reflectivity would have no practical use of the benders.

3 Applicability of benders to a pulsed neutron source

Cold neutron guides also are very useful in the utilization of pulsed source to avoid neutron intensity loss and strong radiation from the source. For example, we could obtain a cold neutron beam with wavelength longer than 4 A and width of 4 cm using a 2Q supermirror guide with length of 15 m. Supermirrors are used in the garland side of the guide to obtain the wide beam width of 4 cm. On the other hand, nickel mirrors in the zigzag side to reduce neutron noise of large divergence. Taking detector position downstream 15m from the pulse source and pulse repetition rate of 25 Hz, the allowable wavelength band width is about 8 A to avoid the frame overlap.

Separating in space longer wavelength neutrons than 12 A by a bender, one guide tube brings us two beam ports of short wavelength component (4A-12A) and long wavelength component. Separating in space + spin neutron beam by a bender with magnetic mirror, non polarized beam brings us two polarized beams with +spin and − spin, which are used for spin echo methods, polarized reflectometry and spin interferometry. Consequently, we could obtain 4 beam ports from one cold guide using three benders, as shown in Fig.3. This shows that the combination of cold guide and benders are very useful for pulsed source, especially, modified neutron spin echo methods and spin interferometry, which can install in relatively small space.

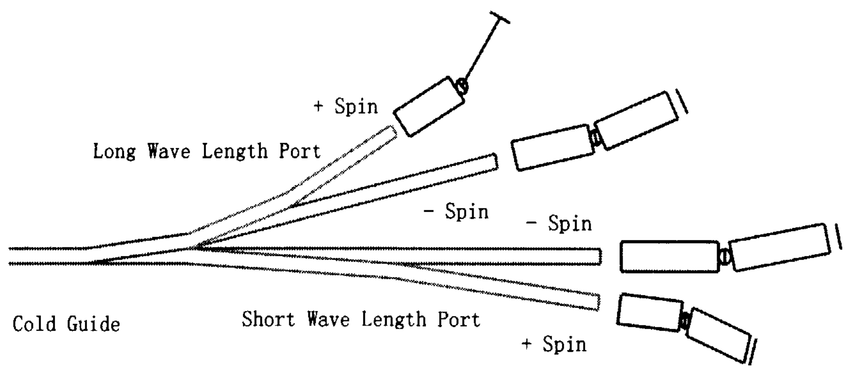

Figure 3: Setup of spectrometers using new benders at a cold neutron guide tube.

Pulsed white neutrons consist of monochromatized neutrons with narrow wand width in time spectrum. This means that usual neutron flippers controlled by current would adapt pulsed white neutrons, applying the flipping current to be inversely proportional to the neutron flight time[9, 10]. It should be noted that spin echo methods should be suitable for pulsed source from the viewpoint of the wide selection of the wavelength region and wavelength resolution in the data processing[11].

So far, benders are used for sequential neutron beams from reactors. Using a bender to obtain monochromatized neutron beam, it is not easy for us to change its wavelength and resolution. Mechanical velocity selector has merit of easy changing the wavelength. On the other hand, benders installed at a pulsed source is not only free from these limits, but also resolve the frame overlap problem, give polarized beams and bring many beam ports. Thus benders are very useful for pulsed source. The development of high quality supermirrors with high Q and high reflectivity is very important to enhance the usefulness of bender [12].

Acknowledgements

This work was supported by the inter university program for the KURRI and JAERI facility, and financially by NOP project by RIKEN and a Grant-in-Aid for Scientific Research from the Japanese Ministry of Education, Science, Sports and Culture(Grant Nos. 10440122 and 11694090).

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