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Novel Three Stage Double Directional Focusing Neutron Monochromator

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Neutron focusing monochromator consisting of three stages of Si-single crystals (with two slabs at each stage), which can provide us continuously variable curvatures in the vertical plane and the bending in the scattering plane, respectively, has been designed and constructed. Each stage can independently be tilted as well as bended by two kinds of mechanical gear systems. The adjustment of both horizontal and vertical curvatures is remotely controlled. The two-axis crystal diffractometer dedicated to strain scanning and installed at supermirror neutron guide tube in KUR has been equipped with this monochromator. By introducing the vertical focusing the detector signal has increased by a factor of two with respect to the previous one-stage version. Design and performance tests are presented.

KEYWORDS: three-stage neutron monochromator, Si-single crystal, double directional focusing

§1. Introduction

Neutron focusing principles and techniques with bent-perfect-crystal (BPC) have strongly been developed and applied to many scattering instruments at steady neutron sources in order to provide benefits of high luminosity and/or resolution due to real and momentum space focusing at the sample position. A considerable gain can be achieved, especially for small samples.[1–3)]

Several different types of four-point benders as focusing elements were used in experiments which were described in recent review papers.[4–7)] A completely different piano wire construction is used in JAERI[8)] and a pneumatic construction for spherical bending in Bucharest and Pitesti.[9)] In comparison with the earlier doubly focusing prototypes,[4,5)] where the approximated vertical curvature was fixed, the advantage of the present monochromator version consists in the independent tunable tilting of each stage of the crystal slabs by remote controlling in order to adjust the vertical as well as the horizontal curvatures independently.

The design of the monochromator and the performance of the diffractometer were optimized for α-Fe(211) reflection in KUR (5MW, light water moderated).

§2. Horizontal and Vertical Focusing

In horizontal focusing of neutrons with symmetric diffraction geometry by a thin cylindrically BPC in real space the general lens formula, $f_h/a + f_h/b = 1$, may be used, where $f_h = (1/2)R_M^h sin\theta_B$ is the focal length, a and b are the distances of the object and image from the curved crystal, R_M^h the radius of curvature and θ_B the Bragg angle, respectively. Then, in diffraction experiments carried out in the horizontal plane by exploitation of focusing in real and momentum space one can easily manipulate with the luminosity of the monochromatic beam at the sample position as well as with the angular resolution with respect to the investigated sample. For example, in the single crystal diffractometry by setting a proper value of R_M^h, the monochromator-sample arrangement can be made dispersion free. On the other hand in powder-crystal diffractometry by manipulation with the bending R_M^h we arrive at an optimum value resulting in a (quasi) parallel beam diffracted by the sample (see details in ref. 10)).

Meanwhile, the vertical focusing only influences the luminosity of a diffractometer without affecting its resolution power. The ray geometry in this case can also be described by the lens formula, where the focal length becomes $f_v = (1/2)R_M^v/sin\theta_B$ and R_M^v is the "vertical" radius of curvature.

In order to fulfill $f_h = f_v$ it appears useful to employ a set of horizontally bent crystal slabs set one above another with the inclination of reflection planes in the vertical plane simulating the vertical curvature. Then, the radii R_M^h and R_M^v are fully independent.

§3. Double Directional Focusing Device

Fig. 1 shows schematic description of vertical section of the three stage focusing device. As can be seen, the mechanical components principally consist of two gear systems, especially designed for the double directional focusing : i.e. the horizontal focusing with one stepping motor and the vertical focusing with 6 stepping motors (2 motors for each stage), respectively. All components of the systems are remotely controlled. The horizontal bending of the three stages is simultaneously achieved by a couple

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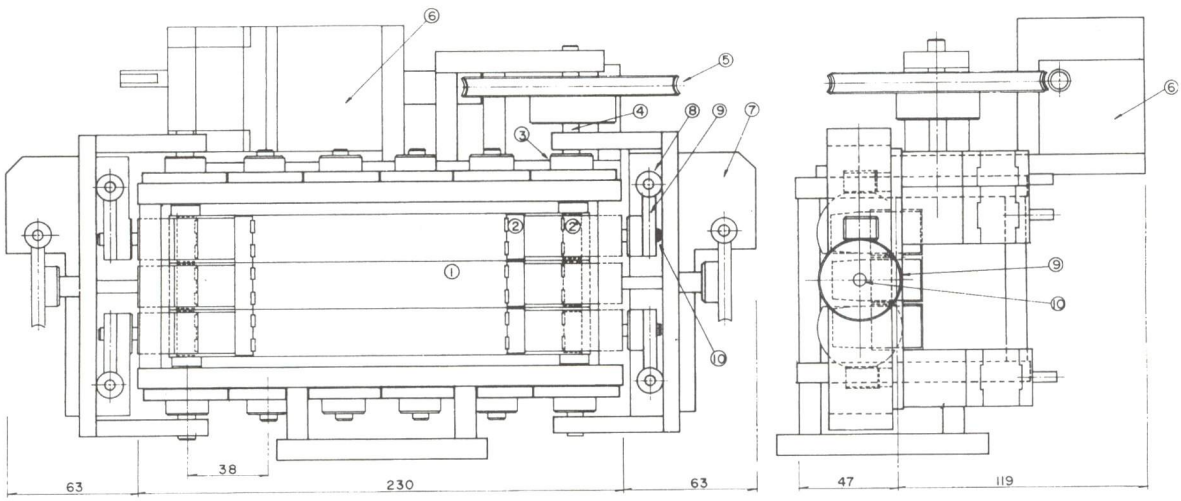

Fig. 1. Schematic description of bending apparatus (vertical section) : 1) bent crystal slabs, 2) 2-2' contact rods for bending (lever parts), 3) gear system, 4) shaft, 5) worm-wheel gear system, 6) stepping motor for bending, 7) stepping motors for inclining, 8) - 9) worm-wheel gear system, 10) rods for inclining.

of lever units (2, 2'). Meanwhile, the vertical focusing is performed by means of an approximation of the vertical curvature by a mutual independent tilting of the slabs at each stage. The advantage of this design is that each stage under bending can independently and remotely be tilted for making possible of an optimum adjustment of variable vertical curvatures in the vertical plane and an optimum use of neutrons distributed in the guide tube. The horizontal focusing system has one stepping motor (gear ratio 1/30, 360 deg./500 pulses, 24 V, 1.4 A) and a gear coupling (1/100, 1/1). This corresponds to the highest angular control of rotation of 2.4×10^{-4} deg./pulse. And the vertical focusing system has 6 stepping motors (gear ratio 1/30, 360 deg./500 pulses, 24 V, 0.3A) and a worm-wheel gear system (1/50). The angular control of rotation is realized as 4.8×10^{-4} deg./pulse. The Si-single crystal slabs installed in the present monochromator are Si(311) : i.e. the largest surface of the slabs is parallel to the 311 planes, 2 slabs in each stage in the form of sandwich, 3Tx23Hx200L mm, 6 slabs in total. Fig. 2 shows a photograph of the device. The present focusing device has the following characteristics : 1) it can be constructed for arbitrary beam height without irradiation of the mounting parts, 2) even for a beam height window larger than 10 cm, no deformation of the device itself has been observed, 3) the new construction permits us an unlimited range of the curvatures, 4) several slabs in sandwich up to the total thickness of 15 mm can be curved in each stage.

The parameters in the present powder diffractometer for strain scanning in KUR are the followings : i.e. the Si(311) crystal slabs of the thickness of 3 mm are used for the focusing monochromator, θ_M=21.5°, λ_M=0.124 nm, L_{MS}=241 cm, scattering angle with respect to α-Fe (211) was $2\theta_S$=61.7°. Using these values, R_M was evaluated as 9.83 m. Calculations of the uncertainties of divergence angle of the quasiparallel diffracted beam gave the value (3.13×10^{-3} rad) almost 5 times better than the one of the earlier conventional performance with mosaic monochromator (1.5×10^{-2} rad).

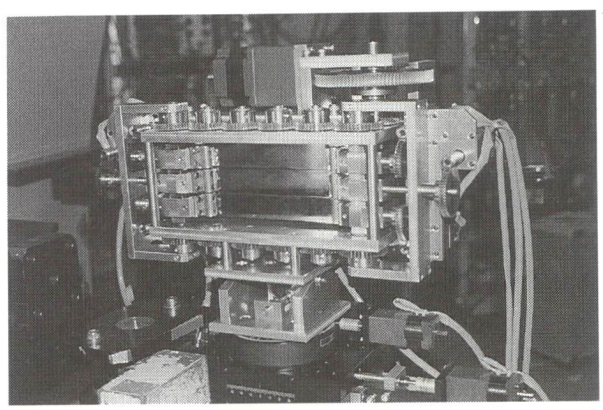

Fig. 2. Photograph of the three stage monochromator.

§4. Experimental Results and Discussion

The optimization performance tests of the present three stage monochromator were carried out on powder diffraction patterns from a standard sample α-Fe(211) plate (2mm thickness), using monochromatic neutrons of 0.12 nm. The patterns were examined by a 1d-PSD at the distance of 80 cm from the sample position. Peak intensity as well as FWHM of the diffraction profiles were measured as a function of the horizontal curvature (see Figs. 3 and 4). In order to minimize the uncertainty coming from the dimension of the sample we used two Cd slits of 2Wx30H mm and 1Wx20H mm placed just before and after the sample. The optimal values are obtained around the number 300 (relative units of the remote control). For a precise horizontal adjustment of the slabs in the stages we used high-resolution dispersion free double-crystal setting with the slightly bent Si(311) slab. The vertical directional focusing effect was tested for each stage separately when tilting the crystal slabs for maximum monochromatic neutron current at the sample position. Table I shows the relative contribu-

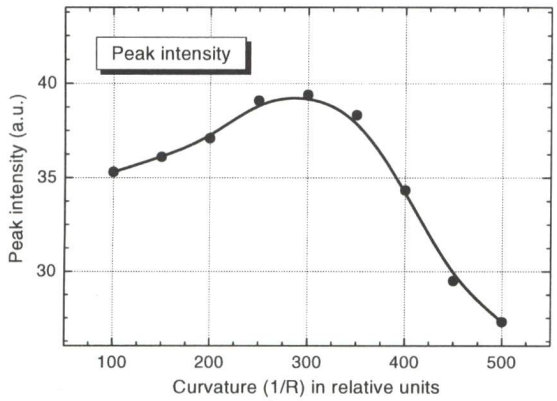

Fig. 3. Diffracted peak intensity as a function of curvature.

tions from the upper, the middle and the low stages to the peak intensity of the diffraction profile, respectively. The middle stage contribution is the best in comparison with the other two stages. It has been found that the differences are brought about by an inhomogeneous distribution of the thermal neutrons within the cross section of the guide tube. Concerning the FWHM values corresponding to the individual stages they provide nearly the same contributions.

The absolute neutron intensity from the monochromator was also evaluated at the same geometrical arrangement at the focusing position of 1.8 m as the case of the previous test for the one-stage monochromator (Version 1), where the neutron intensity was measured by means of the Au - foil activation analysis method with combination of intensity profile imaging plate method.[7] Table II shows the comparison of the evaluated results of the two monochromators, indicating the absolute intensity to be almost 2 times intensive.

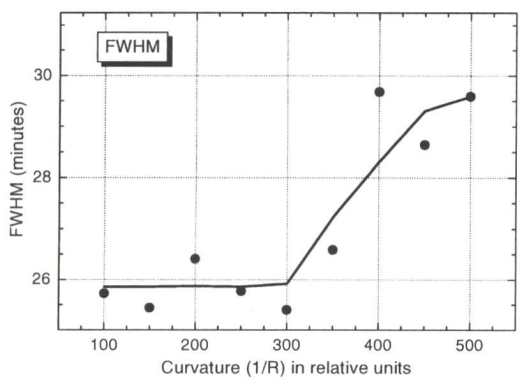

Fig. 4. FWHM of diffracted peak as a function of curvature.

The present high resolution strain scanner has a good resolution and luminosity that permit us to perform peak shift measurement with the sensitivity better than 10^{-4} of the $\delta d/d$ - scale for a reasonable measurement time even at our medium power neutron source at KUR as was demonstrated on the experiment described in ref. 11.

§5. Conclusion

Novel three stage double directional (horizontal and vertical) focusing neutron monochromator with perfect Si-single slabs has been developed and installed on the strain scanner in the supermirror neutron guide hall of KUR. All three stages are cylindrically curved simultaneously and the vertical focusing is achieved by means of an approximation of the vertical curvature by a mutual tilt of each stage. The full mechanical adjustment of the all slabs for the double focusing is remotely controlled. By introducing the vertical focusing, the luminosity of the strain scanner has increased by a factor of two without changing the resolution with respect to the earlier case with one stage monochromator.

TableI. Relative contributions of diffracted neutron intensity and FWHM.

Stage of crystal	Contribution of peak of peak intensity (%)	FWHM (minutes)
Upper	36.0	27.6
Middle	39.4	25.4
Low	24.8	27.6

TableII. Comparison of reflected neutron intensity at L_{MS}=1.8 m from Version 1 and Version 2 monochromators.

	Crystals (mm)	Absolute neutron intensity (10^4 n/cm^2 / sec)
Version 1	4T x 30 H 2 slabs (one-stage)	6.2
Version 2	3T x 23 H 2 slabs (three-stages total 6 slabs)	12

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