FOCUSING OF THERMAL NEUTRONS BY MEANS OF THE CAPILLARY POSITIVE LENS

Arzumanov S.S. [a], Govor L.I.[a], Morozov V.I.[a,b], Panin Yu.N.[a], Strepetov A.N.[a]

[a]NRC "Kurchatov Instute", 1, Akademika Kurchatova sqr., Moscow, Russia
[b]NRNU MEPHI, 31 Kashirskoe sh., Moscow, Russia

The results of investigation of the neutron positive lens in the form of assembly curved glass capillaries are given. Each a capillary represented a conic tube 22.5 cm long with an entrance diameter of 0.25 mm and outlet diameter of 0.17 mm. The spectrum of the thermal neutrons falling on the entrance of a lens was created on beam of IR-8 reactor by means of the diamond microcrystalline filter and was measured by time-of-flight spectrometer. The spatial distribution of a neutron beam at the lens exit was measured by Image Plate detector. The focal length of the lens equal to 75 mm was determined. Possibility of focusing of the thermal neutrons with increasingof local density on axes of beam by 4.9 times is shown.

Capillary x-ray optics is now widely and successfully used in fundamental and applied research, as well as in commercial devices. Recently great interest has been to cause the application of capillary optics for neutrons [1-7]. The first experiments on the deflection of thermal neutrons [1] using curved glass capillaries caused a large number of proposals and experimental studies [2-7] different capillary neutron-optical systems (CNOS).

CNOS represents axisymmetric dense assembling of glass capillaries packed in a cylindrical metal housing. Limiting velocity $V_{\lim}$ of glass is 4.4 m/s, so the neutrons incident on a smooth glass surface with normal velocity component $v_n \le V_{\lim}$ are specularly reflected. Thus for thermal neutrons at a speed of 2200 m/s, the reflection occurs if the neutrons fall on the glass surface at an angle less than the critical $\theta \le 0.002$. When reducing the velocity of the neutrons the critical angle of reflection increases. Neutrons that have passed into the glass either scattered or captured by nuclei. Therefore, by direct capillary due to the reflections propagate the neutron beam, in which the axial component of velocity v_x is arbitrary, but $v_n \le$ 4.4 m/s.

A flexure of capillary without significant loss of intensity of the transmitted beam is possible, until a condition $\sqrt{\frac{2d}{R}} \le \theta$ is carried out, where R is the bending radius of the capillary, d is the internal diameter. Thus, the curved cylindrical capillary may limit coming out of it neutron flux in the axial component of velocity.

Space KNOS, free from the capillaries is filled with a powdery mixture, effectively absorbing and scattering neutrons and γ-rays, for example, tungsten powder, boron carbide and powdered sugar ($C_{12}H_{22}O_{11}$). Filling substances allows to suppress in the neutron beam a background of concomitant reactorγ-radiation, to reduce the fraction of fast neutrons in the formation of beams of thermal neutrons. CNOS can also increase the local density of neutron flux [4]. The capillaries need to be assembled in a configuration that creates, similar to an optical lens, focusing the neutron beam.

A device of the lens with conical smoothly curved capillaries designed for focusing thermal neutronsschematically shows in Fig. 1. The lens is designed and developed by M.A.

Kumakhov and G.I. Borisov at the Institute for x-ray optics. Each capillary is a conical tube of length 22.5 cm with external input diameter of 0.25 mm and outlet diameter of 0.17 mm. Internal input diameter of the capillary is 0.2 mm, outlet diameteris 0.15 mm.All capillaries in the amount of about 570 units are installed in a tightly packed conical assembly with the input diameter of 6.3 mm and the output diameter of 4.3 mm.The capillaries are smoothly curved so that the output directions of their axes converge at a point located at a distance of 75-80 mm (the intended focus point). Peripheral capillaries at the outlet bent at an angle of 1.5° from the original direction, the other ones less curved and the magnitude of curvature decreases when approaching the axis of symmetry.The neutrons pass through the inner space of the capillary, if the normal component of velocity at each collision with the wall is less than 4.4 m/s.Lens itself is placed in a metal cylindrical housing filled with boron carbide powder. The contents provided suppression of thermal neutron flux going on in the housing space outside of the capillaries.

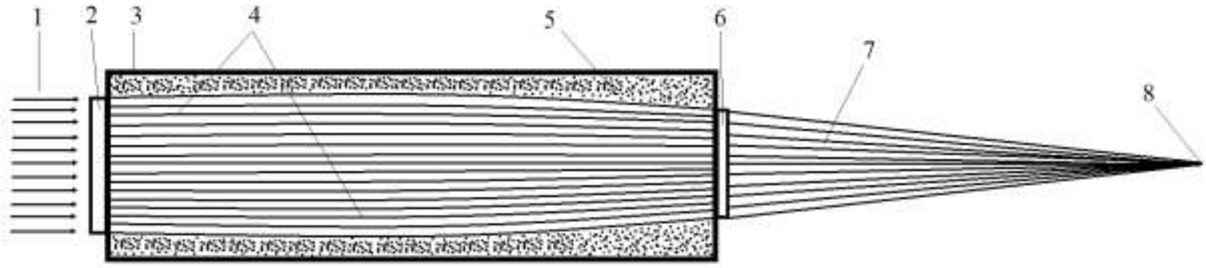

Fig. 1. The schematic structure of lens. 1 - incident neutron flux; 2 - input window; 3 - cylindrical metal housing; 4 - glass capillaries; 5 - boron carbide powder; 6 - outlet window; 7 - neutron flux after the lens 8 - focal spot.

In Fig. 2 shows photographs of the inlet and outlet ends of the lens.

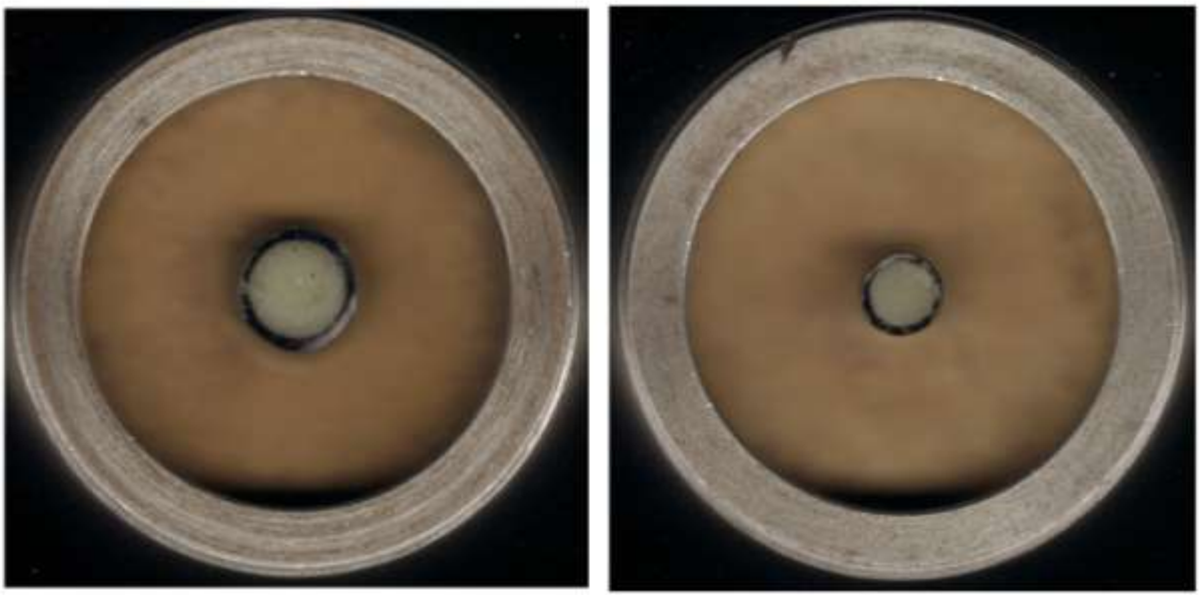

Fig. 2. Photos of the inlet and outlet ends of the lens.

The study of the focusing properties of the lens was performed on the horizontal tangent channel № 7a of the reactor IR-8 NRC "Kurchatov Institute". The scheme of the measurements are presented in Fig. 3. The neutron source was additional beryllium scatterer of neutrons mounted in the channel at a depth of 5.4 m relative to the output beam. Neutrons from the scatterer are passed through steel conical collimator with an input diameter of 80 mm, an outlet diameter of 40 mm and a length of 2.2 m. Further, the neutrons are passed through a steel cylindrical collimator with a diameter of 40 mm and a length of 2 m, in which was set diamond, polycrystalline filter. Filter length is 40 cm. After passing through the filter the neutron beam was formed last steel collimator with a hole of diameter 6 mm and length of 20 cm. At the outlet of the last collimator formed almost parallel neutron beam (angular divergence not higher than 0.55°).

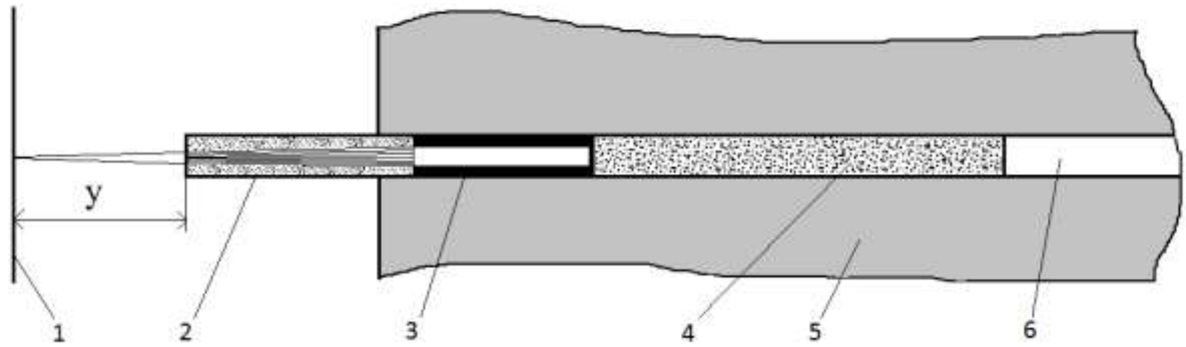

Fig. 3. The scheme of investigation focusing properties of the lens. 1 - Image Plate, 2 - lens, 3 - output steel collimator, 4 - diamond filter, 5 - shielding material; 6 - cylindrical steel collimator.

The spectrum of neutron flux Φ coming from the collimator was measured by time-of-flight spectrometer on the base of 3.4 m with a mechanical interrupter in the form of a rotating cadmium disk. The detection of neutrons was carried out proportional gas detector SNM-18. Diamond filter significantly suppressed the background of fast neutrons and γ-rays coming from beryllium scatterer to the input of the lens and formed neutron spectrum presented in Fig.4.

It is seen from Fig. 4 that after elastic scattering in the diamond filter from the Maxwellian spectrum of neutrons there are two velocity groups of neutrons. The first is concentrated in the interval (400 - 1000) m/s, with the most probable velocity of 950 m/s. Second in the interval (1000 - 1600) m/s, with the most probable velocity of 1500 m/s. When the angular divergence of 0.55° after the collimator normal to the axis of the beam components for the most probable velocities do not exceed 9.0 m/s and 14.3 m/srespectively.

The study of the spatial distribution of flux density in the neutron beam was produced position–sensitive Image Plate detector [8]. The dependence of local neutron flux density N (in relative units) fixed in the plane of arrangement of the Image Plate is presented in Fig. 5. The distribution is cylindrically symmetrical about the beam axis. Y is the distance between the plate of detector and the exit window lens.

The rightmost distribution of the flux density got without lens when Y = 0. The width of the distribution (FWHM) is 6.6 mm, which is slightly larger than the input diameter of the lens. Below are distributions of neutrons density in the beam, obtained by successive increase of the distance Y. When Y = 0 width (FWHM) output flux distribution from the lens is 3.8 mm. At that the total flux of neutrons emerging from the lens is 8 times less than the input. The weakening of the full flow is caused by three factors: a) some of the neutrons misses in the input window of lens, b) some of the neutrons of the input beam enters the space between the capillaries, c) loss of neutrons in the capillaries when they hit the wall, if the normal component of the velocity exceeded 4.4 m/s. This loss factor is essential because the first two factors weaken the total flux is not more than 1.5 - 2 times.

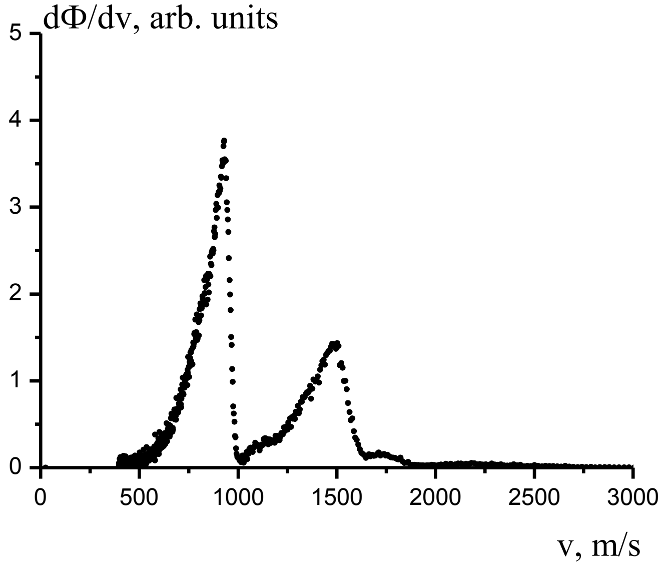

Fig. 4. The neutron flux dΦ/dv coming from the collimator at the entrance of the lens.

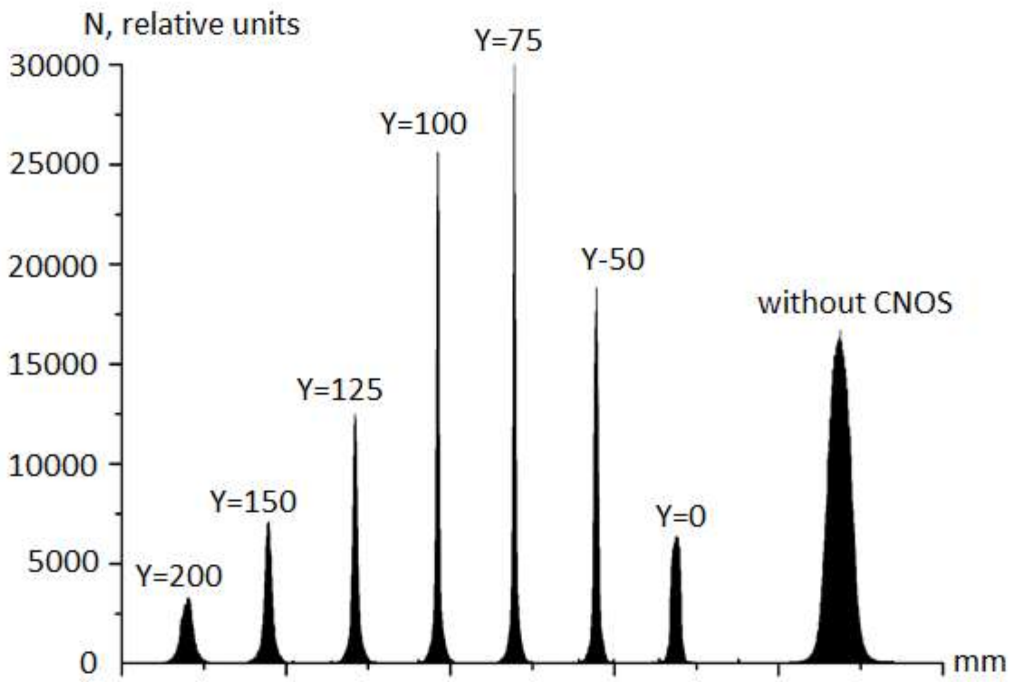

Fig. 5. The neutron flux density vs. distance Y between the lens and the plate of detector.

With increasing Y, the width of the neutron beam decreases and reaches a minimum (equal to0.9 mm) at Y = 75 mm. After passing this point, the beam starts to extend again, although the total neutron flux is remained in it. This suggests that the lens focuses the neutron beam and its focal length F is (75-80) mm.

It is evident that the focus allows to increase the local density of the emergent neutron flux on the axis of a lens in 4.9 times. The ratio of local axial flux densities at the focus point and the entrance of the lens is slightly less and is equal to 1.8.

The gainof local flux density indicates on the possibility of using such lenses for further improvement of their performance in practical and fundamental research with thermal and cold neutrons.

The authors are grateful to V.A. Somenkov with colleagues for providing Image Plate detector and discussion of measurement results.

References

1. Kumakhov M.A., Panin Yu.N., Sharov V.A. Pis’ma v ZhETF, 1990, т. 16, vyp. 10, p. 24 (in Russian).
2. Podurets K.M., Mildner D.F.R., Sharov V.A. Rev. Sci. Instr. 1998, v. 69, n. 10, p. 3541.
3. Peurrung A.J. Med. Phys., 1996, v. 23, n. 4, p. 487.
4. Borisov G.I., Kumakhov M.A, Nucl. Instr. Meth. Phys. Res., 2004, v. A 529, p. 129.
5. Borisov G.I., Kumakhov M.A, ibid, p.98.
6. Borisov G.I., Kumakhov M.A, ibid, p.102.
7. Kumakhov M.A., ibid, p.69.
8. Masalovich S., Ioffe A., Schlapp M. et al. Nucl. Inst. Meth. Phys. Res. A**,** 2005, v. 539, p.236.