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NUCLEAR EXPERIMENTAL TECHNIQUES

First Results of Use of a Scintillating-Fiber Position-Sensitive Detector for Recording the Target Image in a 14-MeV Neuron Beam at the ISKRA-5 Facility

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Abstract—The design of the scintillating-fiber detector is described, and the first results obtained in recording the target image in a 14-MeV neutron beam at the ISKRA-5 facility are presented. The scintillating-fiber position-sensitive detector has been designed for diagnosing laser fusion processes by recording the spatial distribution of thermonuclear neutrons escaping from the target. Position-sensitive detection is effected by conversion of neutron radiation into light in a scintillating fiber array. Discrimination of neutrons from γ rays by their time of flight and image intensification are performed with the aid of a frame camera. Images are recorded by a CCD camera. A technique for recording penumbra images is used for imaging at low neutron yields (3×10^8–10^{11}).

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One of the methods for diagnosing laser fusion (LF) processes consists in recording the image of a target at the instant of its compression. The target image can be recorded in an α, γ, X-ray, or neutron beam. Analyzing the size, shape, and intensity distribution of the target image, one can judge about the properties of the capsule, the conditions of its compression, and the characteristics of the compressed region.

The target image is traditionally recorded in X or α rays. At the instant of compression, the target density increases considerably, so that it exceeds the density of a liquid several hundreds of times. Incidentally, the ranges of α particles and X- and γ-ray photons decrease, and the target becomes opaque to these particles. Neutrons with an energy of 14 MeV have substantially longer path lengths, thus offering a chance to directly record the image of the thermonuclear neutron production region.

A prototype of the scintillating-fiber position-sensitive neutron detector (PSND) has been designed and produced by the Research Institute of Pulse Techniques. The detector is intended for diagnosing LF processes by recording the spatial distribution of thermonuclear neutrons produced in targets [1].

A neutron aperture and a position-sensitive neutron detector are used in LF experiments to obtain the target image in a fast-neutron beam, and special software is used to reconstruct this image.

The neutron aperture forms a target image on the PSND. To provide adequate contrast, the aperture must have a thickness of at least ~2–3 path lengths of 14-MeV neutrons in the aperture material. In our detector, we use a neutron aperture that allows recording of penumbra neutron images at relatively low neutron yields (10^8–10^{11} neutrons per pulse). The high aperture ratio and the simplicity in production are the main advantages of this aperture, and the necessity to reconstruct the target image recorded in a coded form is its drawback.

The diagram illustrating formation of a penumbra neutron image [2] is shown in Fig. 1. The size of the hole in the image-creating aperture being greater than the target size is the specific feature of our technique. Information on the characteristics of the neutron source is coded in the penumbra region. To reconstruct the image, one must resort to additional mathematical processing of recorded data.

A neutron aperture for creating images was produced by the All-Russia Research Institute of Experimental Physics. Tantalum was used as an aperture material. The aperture was assembled from 17 4-mm-thick plates having holes with diameters ranging from 0.6 to 1.2 mm. The plates were located so that the aperture hole had a biconical shape.

The coordinates of the neutron's hit points were recorded with the aid of a PSND, the structural diagram of which is presented in Fig. 2. Neutron radiation is converted into light by scintillating-fiber array *1* [3]. The scintillating-fiber array has dimensions of 150×150 mm and consists of ~20000 square fibers

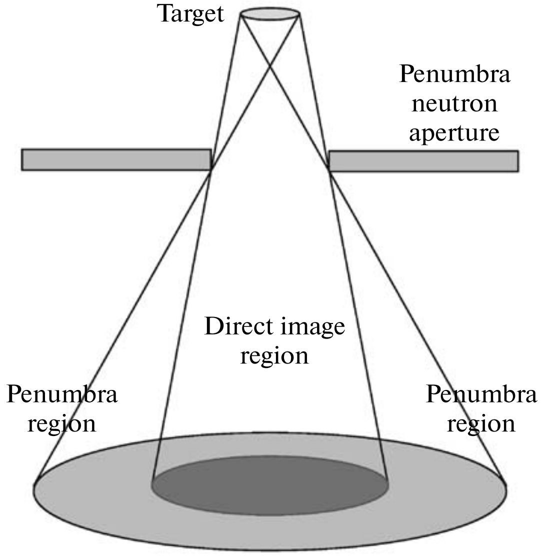

Fig. 1. Schematic diagram of penumbra imaging.

with core dimensions of 1 × 1 mm and a length of 96 mm. A BCF20 scintillating fiber from Saint-Gobain was used to produce the array.

Light is transmitted over scintillating fibers to the back end surface of the array. The image of the array's end surface is transferred with the aid of deflecting mirror *2* and Leptonar-7P projection lens *3* to the photocathode of СФЭР10-01 recorder *4*. The СФЭР10-01 recorder simultaneously performs the functions of a camera shutter and an image intensifier and allows discrimination between γ rays and neutrons by their time of flight. The diameter of the СФЭР10p01 photocathode is 40 mm. The shutter-opening time is specified stepwise: 5, 10, 20, 50, 100, 200, and 500 ns. The gain has smooth regulation from 500 to 10^6. The quantum efficiency of the photocathode is 10% at a wavelength of 450 nm.

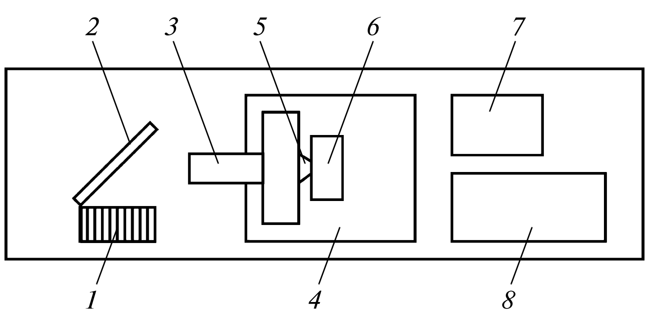

Fig. 2. Structural diagram of the scintillating-fiber position-sensitive detector for fast neutrons: (*1*) scintillating-fiber array, (*2*) mirror, (*3*) Leptonar-7P lens, (*4*) СФЭР10-01 recorder, (*5*) focon, (*6*) CCD-array sensor of the СПМ16 recorder, (7) control crate of the СПМ16 recorder, and (*8*) uninterruptible power supply.

The intensified image is recorded by CCD-based СПМ16 recorder *6*. The dimensions of the CCD array in the СПМ16 recorder is 1024 × 1048 pixels with a cross section of 16 × 16 μm^2. Focon *5* is used for mating the dimensions of the CCD array of the СПМ16 recorder and the luminescent screen of the shutter.

The control crate of the СПМ16 recorder is integrated into a local-area network with a data acquisition computer, which is situated in an isolated room at a distance of ~50 m from the target chamber. The control crate of the СПМ16 recorder communicates with the data acquisition computer via a fiber-optic communication link.

The СФЭР10-01 and СПМ16 recorders are powered from an uninterruptible power supply.

Reconstruction of a penumbra neutron image is based on the inverse convolution method according to the Richardson–Lucy algorithm and involves built-in functions of the MATLAB package [4, 5].

Using the above technique, penumbra neutron images were recorded in a set of 12-channel experiments at the ISKRA-5 facility. The positions of the neutron aperture and the PSND relative to the target are shown in Fig. 3.

The distance from the target to the end surface of the scintillating-fiber array was 637.5 cm and the target-to-aperture distance was 8.6 cm. The СФЭР10-01 recorder was triggered by an electric pulse from a photocell located in a laser beam. The length of the cable line used to delay triggering of the СФЭР10-01 was 12.5 m. Discrimination between γ-ray and neutron radiation was effected by the time of flight. The amplification in the СФЭР10-01 was 5 × 10^4.

Images of the fusion target were recorded in a set of three experiments. The target filled with a D–T gas mixture at different pressures was used in each experiment. The recording conditions differed in the frame duration in the СФЭР10-01 recorder, which varied from 10 to 50 ns.

The highest possible spatial resolution on the target is directly proportional to the doubled detector resolution and inversely proportional to the enlargement factor of the imaging system [6].

The detector resolution for fast (14 MeV) neutrons is governed by the size of the scintillating components and the path length of recoil protons in this scintillator. The path length of a recoil proton in the scintillator perpendicularly to the direction of a 14-MeV neutron is ≤0.65 mm. Therefore, the proton energy will be deposited in no more than to adjacent fibers (2 mm). If the enlargement factor of the system is ~60, the highest possible resolution on the target will be ~70 μm. Apart from the detector resolution and the enlargement factor of the imaging system, the quality of the reconstructed image depends on the number of neutrons participating in the imaging process.

In the set of the experiments conducted at the ISKRA-5 facility with the aim of recording target

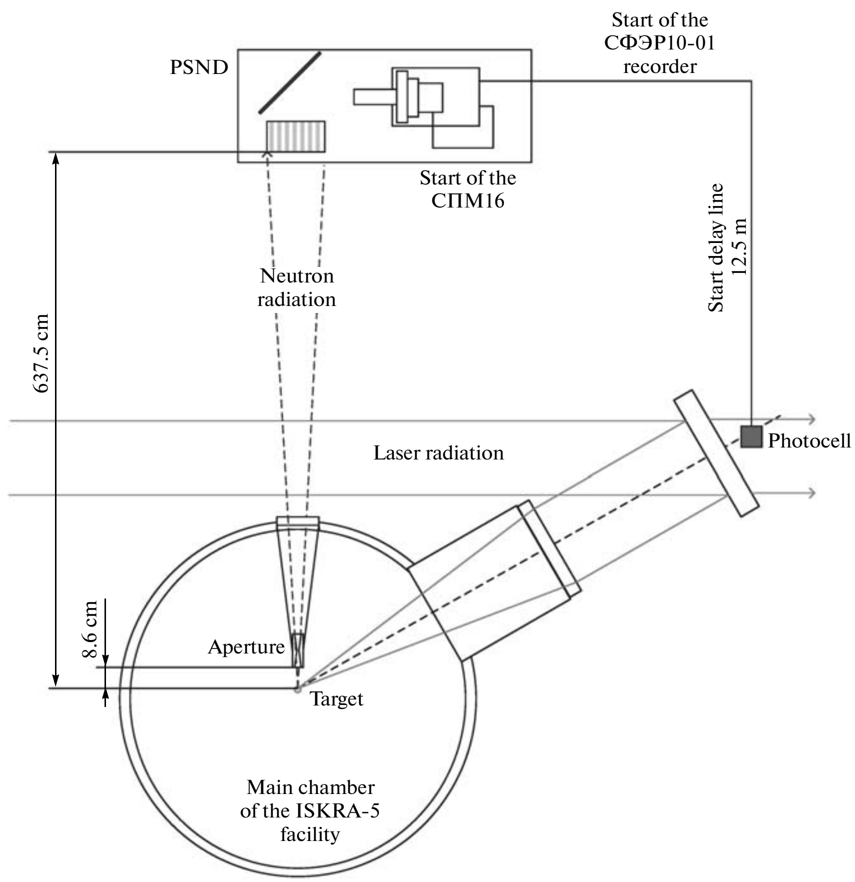

Fig. 3. Layout of experiments on recording of neutron images at the ISKRA-5 facility.

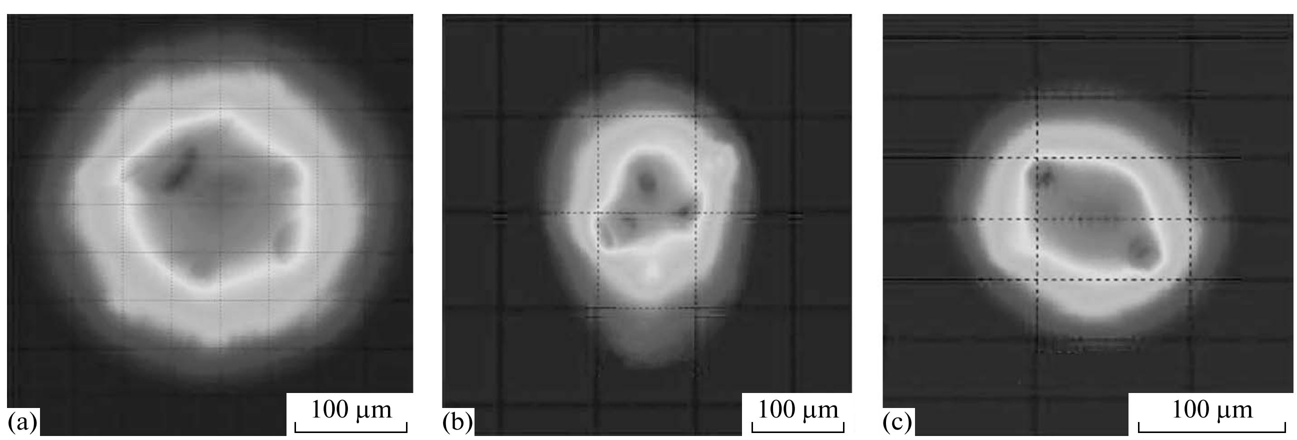

Fig. 4. Reconstructed target images in a beam of 14-MeV neutrons in the experiments at the ISKRA-5 facility at a frame duration (a) of 50, (b) 20, and (c) 10 ns.

images, the yield of 14-MeV neutrons was ~5×10^9. Figure 4 presents the images of the target in a beam of 14-MeV neutrons, recorded in a set of three experiments and reconstructed according to the Richardson–Lucy algorithm. These images make it possible to estimate the dimensions and shape of the neutron generation regions.

Based on results of tests at the Research Institute of Pulse Techniques, the PSND prototype was updated: the end surfaces of the scintillating-fiber array were additionally polished, and a mirror was mounted at the front end surface of the array. This has made it possible to increase the detection efficiency to a value of ~20%. Today, a new СПМ20 recorder with a larger (28.5×28.5 mm^2) CCD array has been developed by the Research Institute of Pulse Techniques, the use of which will allow us to dispense with a focon.

For the resolution of the imaging system to be increased in the next experiments aimed at recording neutron images at the ISKRA-5 facility, it is expedient that the PSND be placed at a larger distance from the interaction chamber.

As a result, the technique for recording penumbra neutron images of the target has been tested in the experiments at the ISKRA-5 facility, the penumbra image of the target in a beam of 14-MeV neutrons has been recorded for the first time with the aid of the scintillating-fiber position-sensitive detector, and the penumbra target image has been reconstructed using the inverse convolution method based on the Richardson–Lucy algorithm.

REFERENCES

1. Disdier, L., Rouyer, A., Fedotoff, A., and Bourgade, J.-L., *Rev. Sci. Instrum.*, 2003, vol. 74, no. 3, p. 1832.
2. Morgan, G.L., Berggren, R.R., Bradley, P.A., et al., *Rev. Sci. Instrum.*, 2001, vol. 72, no. 1, p. 865.
3. Ress, D., Lerche, R.A., Ellis, R.J., and Heaton, G.W., *Rev. Sci. Instrum.*, 1995, vol. 66, no. 10, p. 4943.
4. Zhao, Z., Ding, Y., Dong, J., et al., *Plasma Phys. Control. Fusion*, 2007, vol. 49, p. 1145.
5. Gonzalez, R.C., Woods, R.E., and Eddins, S.L., *Digital Image Processing Using MATLAB*, Upper Saddle River: Prentice Hall, 2003, 1st ed. Translated under the title *Tsifrovaya obrabotka izobrazhenii v srede MATLAB*, Moscow: Tekhnosfera, 2006.
6. Ghilea, M.C., Sangster, T.C., Meyerhofer, D.D., et al., *Rev. Sci. Instrum.*, 2008, vol. 79, p. 023501.