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МЕТОДИКА ФИЗИЧЕСКОГО ЭКСПЕРИМЕНТА

CONTROL SYSTEM OF PELLETIZED COLD NEUTRON MODERATOR AT THE IBR-2 REACTOR

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The unique pelletized cold neutron moderator CM-202 at the IBR-2 reactor was put into test operation and has already worked for more than 2000 h. Normal, fast and trouble-free operation of the cryogenic moderator requires strict adherence to technological conditions (fast charging and discharging of the moderator chamber, maintenance of the required temperature and pressure in different parts of the cryogenic system). The system of control and measuring equipment, designed for the cryogenic moderator of the IBR-2 reactor, satisfies all the requirements and is simple to use. Access to the system of measuring instruments is organized via network. The working cycles of the moderator confirmed the reliability and stable operation of the whole control system.

Уникальный шариковый холодный замедлитель нейтронов КЗ-202 на реакторе ИБР-2 запущен в опытную эксплуатацию и уже отработал более 2000 ч. Нормальная, быстрая и безаварийная работа криогенного замедлителя требует строгого соблюдения технологических условий (загрузка и выгрузка замедлителя, поддержание необходимой температуры и давления на разных участках системы). Система контрольно-измерительной аппаратуры, разработанная для криогенного замедлителя реактора ИБР-2, удовлетворяет всем требованиям и проста в использовании. Доступ к системе контроля замедлителя организован через сеть интернет. В процессе рабочих циклов реактора ИБР-2 подтверждена надежность и стабильность работы всей системы контроля замедлителя.

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INTRODUCTION

A high-performance cryogenic moderator for the IBR-2 reactor [1, 2] has been developed at the Frank Laboratory of Neuron Physics.

Figure 1 presents a layout of the cryogenic moderator.

The pelletized cryogenic moderator is a chamber filled with small solid sphere beads 3–4 mm in diameter made from frozen mixture of mesitylene and m-xylene. The beads are cooled to a temperature of about 30 K. The parallelepiped chamber of the moderator measures 150×180 mm, the thickness for beads is 40 mm. The chamber is heat-insulated by high vacuum volume. The cryogenic moderator consists of both helium loops: primary one,

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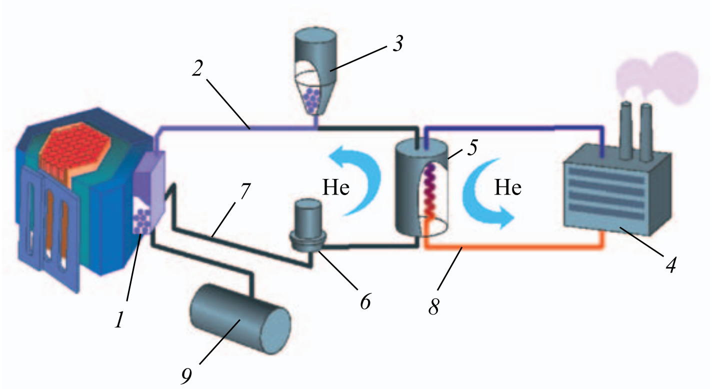

Fig. 1. Layout of the cryogenic moderator: *1* — chamber of the moderator; *2, 7, 8* — gas helium transfer lines; *3* — electromechanical charging device; *4* — helium cryogenic refrigerator KGU-700; *5* — heat exchanger; *6* — helium blower; *7* — primary helium loop; *8* — secondary helium loop; *9* — receiver. Transfer line *2* is specially designed for pneumatic transportation of mesitylene beads to the moderator chamber

which is cooled by the refrigerator KGU-700, and secondary one. The secondary loop driven by blower has thermal contact with the primary one through a recuperative heat exchanger. Cold helium and beads are fed through transfer lines.

The moderator chamber is charged with mesitylene beads by means of pneumatic transportation. A special electromechanical charging device provides quasi-periodic small batch injection of beads into gas helium flow [3].

At the initial stage of work, the cold chamber of the charging device is filled with beads at nitrogen temperature. Then 30–32 K helium flows through the beads; therefore, they are purified from nitrogen. Then beads are transported to charge the chamber of the moderator. Charging continues for 5 h. The bottom side of the moderator chamber is made in the form of netting with the size of cells less than the size of the beads (3 mm).

After neutron session the helium flow is cut off, mesitylene melts by nuclear heat and drains from the chamber into the receiver. The chamber and the whole conveying loop are cleaned from hydrocarbon remains by the flow of warm helium and pumping. Then operating is repeated.

Pneumatic transport of the balls was investigated in [4]. Parameters of gas flow and geometry of transfer lines were determined as well. Transportation of mesitylene beads and charging of a chamber were studied on a stand [9].

1. CONTROL SYSTEM

The requirements for the control system of the cryogenic moderator are the following:

— fast and trouble-free charging and discharging of the moderator chamber;

— fast detection of the jamming in the transfer line;

— maintenance of the required temperature and pressure in different parts of the cryogenic system in the process of the reactor cycle;

— saving data;

— remote access.

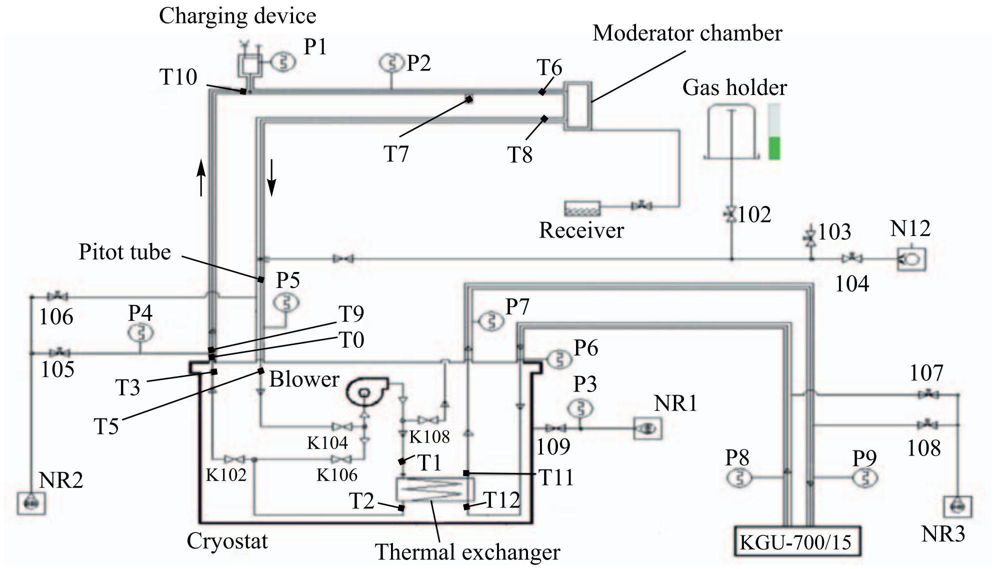

Fig. 2. Technological scheme of the cryogenic moderator

Technological scheme of the cryogenic moderator is shown in Fig. 2. In this figure T — points of temperature measurements; P — points of vacuum measurements; NR1, NR2, NR3 and NI2 – vacuum pumps; *1* — helium transfer line for mesitylene beads transportation; *2, 3, 4* — gas helium transfer line. Direction of helium circulation is marked with arrows, the main units are signed.

2. VACUUM

Control of vacuum in the cryostat and shells of transfer lines is realized by MicroPirani type sensors in the pressure range from 10^{-5} mbar to 1 bar in eight points of the transport lines (P2–P9 in the technological layout, Fig. 2). Communication with external devices can be performed via RS-485 and RS-232 interfaces.

Measurement of helium pressure inside the transfer line is realized by MicroPirani/Piezo type sensors (P1 in the technological scheme). Measuring pressure range is from 10^{-5} mbar to 1.3 bar (working pressure of helium is about 1.01 bar).

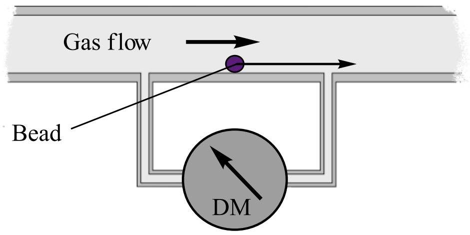

Fig. 3. Principal scheme of control of the balls movement

3. MOVEMENT OF THE BALLS

To control a ball movement inside a tube of the transfer line, the differential pressure is measured between two points located at a few centimeters from each other (Fig. 3) by diaphragm sensors [5].

If the bead moves along the measuring section, then a pressure difference of ∼ 1 Pa appears.

The sensor gives continuous analog signal 0–5 V, which corresponds to the range of 0–25 Pa with the accuracy of 0.5%. The received signal is digitized with a frequency of 1 kHz and transmitted to the PC through USB interface. When the bead goes through the measured point, the sensor signal has a characteristic form with minimum and maximum (Fig. 4).

The transfer line has a complex form (bends, descents and ascents), so a jamming of moving beads is possible. The bead movement is controlled in two points of the transfer line to prevent the jamming: directly after the charging device and before the main ascent, where the jamming is the most probable.

The use of sensors can monitor the process of charging of the chamber, control the existence of balls in the transfer line and identify the presence of jamming quickly.

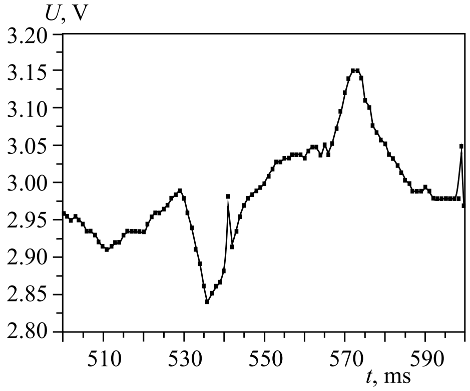

Fig. 4. Signal from the diaphragm sensor indicates the presence of the bead

4. HELIUM FLOW

Helium flow in the transfer line is measured by an installed Pitot–Prandtl tube connected with sensor of differential pressure and special software. In the charging mode the value of gas should be 2–3 g/s.

Circulation of helium through the transfer lines is realized by helium blower. It gives a flow rate of helium at a temperature of 30–40 K up to 5–5.5 g/s at the hydraulic resistance of the circuit 0.08 bar. The blower is equipped with variable frequency drive with controller for motors up to 400 W.

5. THERMOMETRY

Type-K thermocouples are used for the temperature control at 4 points of the gas helium transfer line where there is high radiation. The temperature of the warm ends of the thermocouples is measured by a calibrated platinum thermometer in a special thermostat with accuracy not worse than 0.1 K at room temperature. Initially, the thermocouple had a table feature from room temperature to 77 K. For the calibration of thermocouples, experiment was conducted by cross-linking with a calibrated RuO thermometer in the temperature range 20–40 K and silicon diode DT670A in the temperature range 40–300 K in an SSR cryostat. This gives the accuracy of controlling the temperature of about 1 K at 20 K.

Silicon diodes DT670A are used for temperature measurement in the cryostat of the cryogenic moderator.

Thus, the measurable temperature range in the cryogenic moderator is 20–300 K, which corresponds to the operating temperatures of the system.

All the thermocouples and diodes are connected to a multi-channel multimeter, which allows one to simultaneously measure 10 signals. All data are acquired in special software for data collection and visualization.

6. DATA CONTROL

Signals of all the devices are transmitted to one PC. All information about of the moderator system state displays on a mnemonic scheme. Control of the executive mechanisms (charging device, helium blower) is carried out from another PC. The data is performed as graphs and figures, alarm messages, and stored in the file. For this purpose the appropriate software is developed. In addition, access to measuring data from other remote computers is available via network.

7. OBSERVATION SYSTEM OF CM CHAMBER

During the operation of the cryogenic moderator a number of tasks arose:

1. To receive two-dimensional images of the loaded mesitylene to control the filling of the chamber.

2. To measure the neutron spectrum from the moderator at different temperature of the mesitylene. To record the change of neutron spectrum within the cycle of the reactor (degradation of the spectrum).

3. To control the process of annealing and drain of the mesitylene after the cycle of the reactor.

The system is desinged on the principle of the camera obscura. A two-dimensional image of the surface of a moderator is formed on a position-sensitive detector when thermal and cold neutrons from the moderator pass through a small (about 0.5 mm) horizontal slit in the cadmium diaphragm [6]. The image is inverted; its scale is determined by the distances between the PSD, the diaphragm and the moderator. Figure 5 presents a simplified layout of the experiment on obtaining images of the moderator and neutron spectra using the diaphragm with a slit. Shielding and collimators of borated polyethylene are used to reduce the background. Vacuum volume, which occupies the main part of the neutron path, reduces the loss of neutrons in the air.

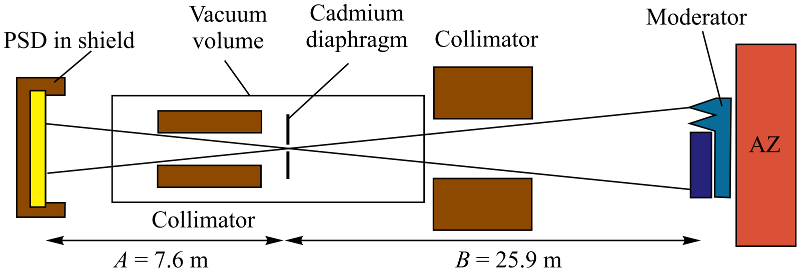

Fig. 5. Layout of the experiment with a gap on the 8th channel of IBR-2

Fig. 6. PSD in shielding installed on the 8th channel

Neutron energy is measured by using the time-of-flight method.

Equipment is installed on the 8th channel of the IBR-2 reactor, the axis of which is orthogonal to the face plane of a moderator. The position-sensitive detector has a working area of 180×180 mm. It is placed so that the centre of the detector is on the horizontal axis of the spectrometer (Fig. 6).

The electronic block of data acquisition consists of a discriminator, high voltage unit, block of delays and power supply, installed in a NIM crate, and personal computer (PC) with PCI data acquisition board. A signal from the detector, together with signals of the reactor starts, is transmitted to the PC where it is processed by DeLiDAQ software [7]. Time-of-flight spectrum and 2D image of thermal neutron flux are measured simultaneously.

The obtained two-dimensional image of thermal neutrons is shown in Fig. 7. The figure shows the correspondence between image and real moderator chamber. The lower half of the image (green color) is formed by cold neutrons which are flying out of mesitylene.

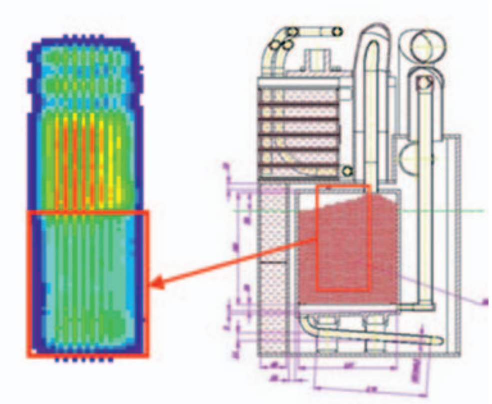

Fig. 7 (color online). Correspondence between image and moderator chamber. Rectangle shows the working medium of the moderator. The image is obtained with neutrons of $\lambda = 0.7$ Å and higher

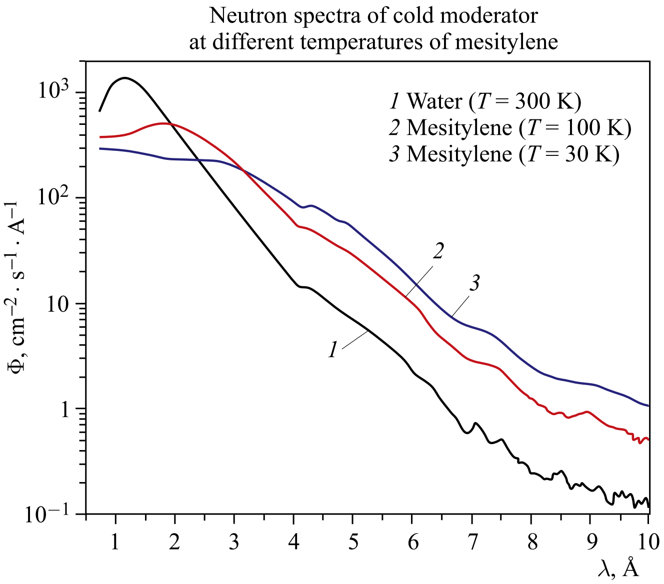

Fig. 8. Neutron spectra obtained from the surface of the cryogenic moderator

In Fig. 7, one can clearly see the level of mesitylene in the chamber.

Spectra of the new cryogenic moderator were obtained in experiments on the beam (Fig. 8). The gain of cold neutron flux and decrease of thermal neutron flux were determined for temperatures of mesitylene equal to 30 and 100 K.

A control system for the chamber of the cryogenic moderator with the method of camera obscura is created. It operates in normal mode on IBR-2 at present.

The first results of operation of the cold moderator are described in [8]. Neutron spectra of the cryogenic moderator were measured at different temperatures of mesitylene. Addition of the cold moderator to the water premoderator gives a gain factor of cold neutrons of about 13. 2D images of the moderator's working substance were obtained; it allowed control of filling and draining of the chamber.

CONCLUSIONS

The control and measuring system for the cryogenic moderator of IBR-2 is ready to use. It allows observing the state of the cold moderator during operation and satisfies all the requirements. The first results — images of mesitylene and spectra of the neutron flux from the cold moderator — are obtained. Measurements during the operating cycle of the reactor have confirmed the reliability and stable operation of the whole system.

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REFERENCES

1. *Kulikov S., Shabalin E.* Complex of Neutron Moderators for the IBR-2M Reactor // Proc. of the 17th Meeting of the Intern. Collab. on Advanced Neutron Sources, ICANS-XVII, Santa Fe, New Mexico, 2005; Rom. J. Phys. 2009. V. 54, No. 3–4. P. 361.

2. *Shabalin E. P. et al.* Pelletized Cold Neutron Moderators for the IBR-2M Reactor // Proc. of the 6th Intern. Workshop on UCN&CN Physics and Sources, Saint Petersburg, Moscow, 2007; http://cns.pnpi.spb.ru/ucn/articles/Shabalin.pdf.
3. *Fedorov A., Kulikov S., Shabalin E.* Patent Application "Cryogenic Dispenser Balls" with priority 21.02.2012.
4. *Kulikov S. et al.* Full Scale Model of Pelletized Cold Neutron Moderators for the IBR-2M Reactor // Proc. of the Intern. Collab. on Advanced Neutron Sources (ICANS XIX). PSI, Grindelwald, Switzerland, 2010.
5. *Petukhova T., Shabalin E., Shirokov V.* Patent #2487430 "Gas-Dynamic Method for Registration of Balls Moving in a Cylindrical Tube" with priority 27.03.2012.
6. *Fuzi J.* Direct Measurement of Cold Neutron Moderator Spectra // Nucl. Instr. Meth. A. 2008. V. 586. P. 41–45.
7. *Levchanovsky F. V. et al.* Software Modules of DAQ PCI Board (DeLiDAQ) for Position-Sensitive MWPC Detectors with Delay Line Readout // Nucl. Instr. Meth. A. 2006. V. 569. P. 900–904.
8. *Ananiev V. et al.* The World's First Pelletized Cold Neutron Moderator at a Neutron Scattering Facility // Nucl. Instr. Meth. B. 2014. V. 320. P. 70–74.
9. *Kulikov S. et al.* Test Stand of the Technological System of the Cryogenic Moderator with the Control Electronics // J. Sci. Arts. 2011. No. 3(16). P. 339–346.

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