NOVEL DEVELOPMENT AND CONSTRUCTION OF EQUIPMENT FOR THE SPECTROMETER COMPLEX OF THE IBR-2 FACILITY

At the 40th meeting of the PAC for Condensed Matter Physics a detailed report on theme 1075 for 2009-2014 as well as the justification and proposal for opening a new first-priority theme "Development of Experimental Facilities for Condensed Matter Investigations with Beams of the IBR-2 Facility" for 2015-2017 (these materials are available at http://indico.jinr.ru) were considered and approved. Below are the results of activities carried out in 2014 in the main research areas of the theme.

Cryogenic moderators

In 2014, studies were conducted on an experimental full-scale test stand of cryogenic pelletized moderator CM-201 (**Fig. 56**).

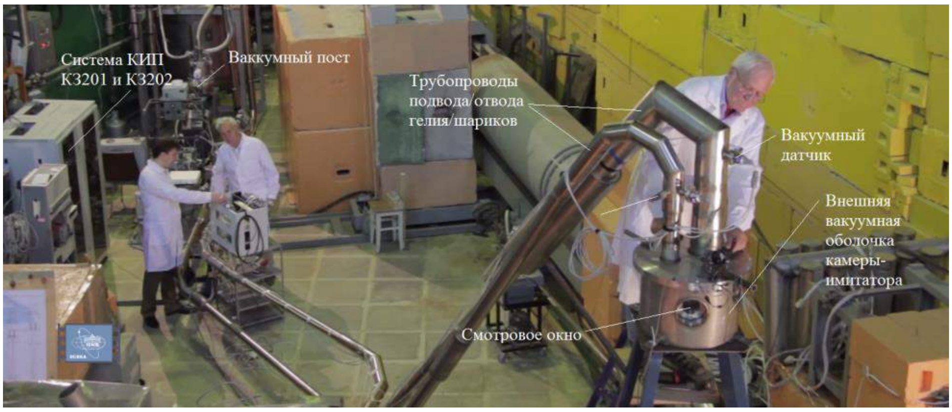
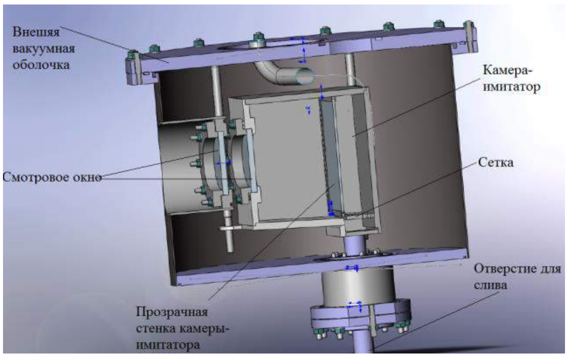


Fig. 56. Full-scale stand of CM-201 (control and measurement equipment of CM-201 and CM-202; vacuum station; helium/bead feed/discharge pipes; observation window; vacuum sensor; outer vacuum jacket of simulator chamber).

The main purpose of the experiments was to test the possibility of loading the chamber of the cryogenic moderator CM-201 with frozen beads made of a mixture of mesitylene and metaxylene by transporting them through a pipeline ascending at an angle of 50°. The experiments have shown that beads without difficulty move up the inclined section of the transport pipeline and reach the simulator chamber located inside the outer vacuum jacket (**Fig. 57**). The filling of the simulator chamber was monitored by a high-resolution camera (**Fig. 58**).

The cryogenic moderator CM-202 has been in operation since 2012. In 2014, its control systems and software were upgraded. As a result, control systems for CM-202, CM-201 and cryogenic helium facility (KGU) have been developed practically anew and accommodated in the common electronic equipment rack (**Fig. 59**). They also include the CM emergency monitoring system, which controls the circulation of helium in the system and its flow rate in the pipeline. If these parameters go beyond the allowable limits, the control electronics sends a signal to the IBR-2 control panel to reduce the reactor power. In 2014, CM-202 operated for physics experiments during two cycles (2 and 7 cycles of IBR-2 operation). At the same time, first experiments with cold neutrons were carried out at the spectrometers NERA-PR, REMUR and others. Also, important studies were conducted aimed at extending the cycle duration of IBR-2 operation in the cryogenic mode up to 11 days.



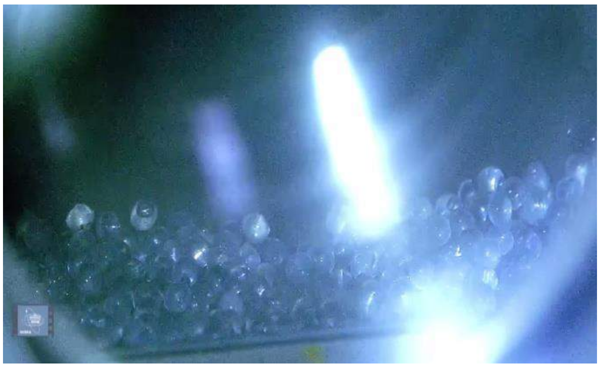


Fig. 57. Simulator chamber (observation window; outer vacuum jacket; simulator chamber; grid; discharge vent; transparent wall of simulator chamber).

Fig. 58. Photo of frozen beads being loaded into the chamber.

At present, the maximum duration of CM-202 operation is 410 MWh (8.5 days of IBR-2 operation). The possibility of increasing the cycle duration depends on the viscosity of the irradiated working mixture (metaxylene and mesitylene) of the moderator. The viscosity of the metaxylene-mesitylene mixture after irradiation is about 12 arb. units (8.5 days, 410 MWh). This value of viscosity allows the irradiated liquid to flow freely from the chamber to a discharge tank. It is possible that higher values of viscosity can lead to the clogging of the discharge outlet and consequently result in a failure of the CM-202 operation.

In order to find a way out of this situation, a number of experiments were performed on loading the CM-202 chamber with frozen beads consisting of a solution of 55 g of naphthalene and 1 l of metaxylene-mesitylene mixture (in the ratio of 3:1). After irradiation for 374 MWh the viscosity was found to be about 6 arb. units, i.e., sufficiently low compared to the viscosity of the irradiated solution without naphthalene (**Fig. 60**).

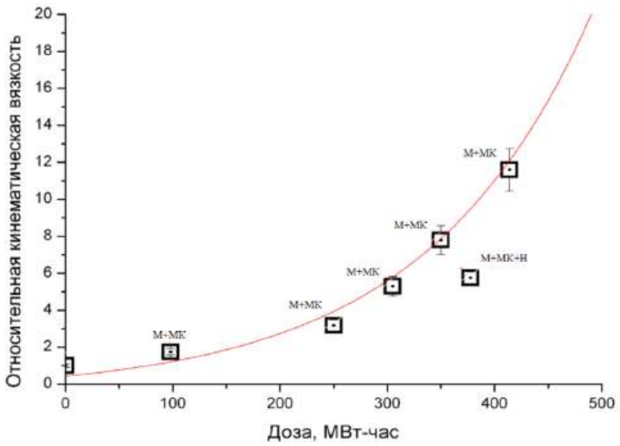


Fig. 59. Control electronic equipment racks for CM-201, CM-202 and KGU.

Fig. 60. Dependence of viscosity of the liquid mixture on the radiation dose liquid mixture on the radiation dose: M-MK- mesitylene-metaxylene solution (in the ration of 3:1), M-MK-H - solution of 55 g naphtalene dissolved in 1 L of mesitylene-metaxylene mixture (in the ratio of 3:1).

Thus, the solution with naphthalene can be used for longer operation time of IBR-2 and maybe even for 11 days. Experiments to extend the duration of the CM-202 operation cycle will be continued in cooperation with Moscow State University in 2015.

Calculations and simulation of spectrometers

A technique using the Reverse Monte Carlo (RMC) method to reconstruct a 3D structure of glasses (or other disordered systems) using neutron diffraction data has been developed. A special program has been developed, which allows one to determine coordination of glass atoms using Voronoi networks. If necessary, there is an option to construct a Voronoi tessellation taking into account ionic radii of particles. In this case we used some functions of the specialized software library Voro++. An example of calculations of the total scattering law S(Q) (or its analog – total structure factor F(Q)) by the RMC method for $Fe_{63}Er_2Mo_{14}C_{15}B_6$ glass in comparison with the experimental data is shown in **Fig. 61**. **Figure 62** presents a general example of a 3D Voronoi tessellation constructed with regard for ionic radii of particles (different colors represent different elements).

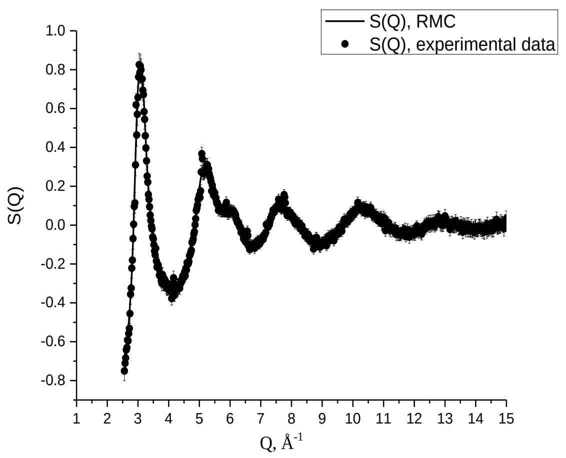


Fig. 61 Experimental total scattering law S(Q) and its calculation using RMC_POT program.

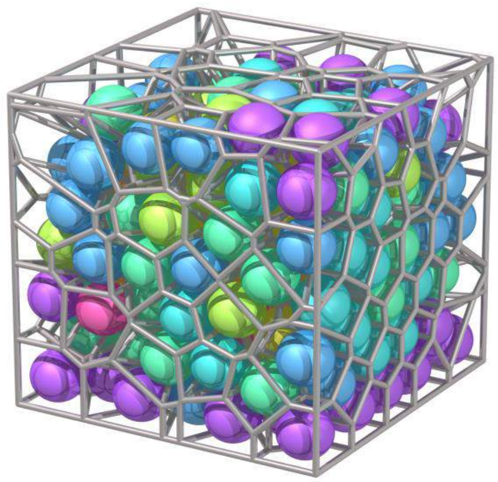


Fig. 62 Example of a constructed Voronoi tessellation.

In cooperation with the Laboratory of Information Technologies, JINR, we started the development of special mathematical models and respective programs for simulating neutron scattering in samples (including multilayer rough samples) and magnetic scattering. First results of the simulation of two-layer rough samples were obtained.

In 2014, in cooperation with the NICM Department a number of activities on the modernization and development of the Fourier diffractometer were carried out.

FSS. Work was continued on the construction of a new high-resolution Fourier diffractometer on the basis of the units of the FSS spectrometer (Geesthacht, Germany). The received equipment was inspected and design studies of its installation on IBR-2 beamline 13 were performed. The optical sections and housings of the neutron guides were cleansed and degreased. Additional sections and support posts of the neutron guides were manufactured. In order to reduce the radiation load on the neutron guide, a steel collimator was installed in the embedded tube of the beamline. The first section of the neutron guide and a Fourier-chopper were assembled and installed (**Fig. 63**). The electronics for accumulation of diffraction spectra («List Mode»-analyzer MPD-64) were designed and manufactured.

On the same beamline the infrastructure for testing spectrometer equipment is under construction. A biological shield and technological systems were installed on IBR-2 beamlines 13 and 14; the manufacturing of an experimenter's cabin, platform, adjustment tables, etc. is in progress.

Fig 63. First section of the neutron guide and Fourier-chopper on IBR-2 beamline 13.

HRFD. Control electronics of the background chopper were installed. The preventive maintenance of the background chopper and the adjustment of the control electronics in the phasing mode were performed. The operation of the control electronics of the Fourier chopper was restored due to the installation of a fast neutron background chopper in the ring corridor and reduction of the radiation background in the area of the beam outlet.

FSD. The characteristics of pickup signals from magnetic and optical sensors of the Fourier chopper were measured. The time dependence of differential nonlinearity and the duty ratio of pickup signals from magnetic and optical sensors as the speed of the Fourier chopper changes from –4000 to +4000 rev/min are shown in **Fig. 64** and **Fig. 65**, respectively. The measurements have shown that the noise of pickup signals from the optical sensor is approximately five times lower than that from the magnetic one. The activities for developing the detector system of FSD and designing algorithms and programs for extracting high-resolution spectra measured by a "list-mode" analyzer are covered in other sections of this report.

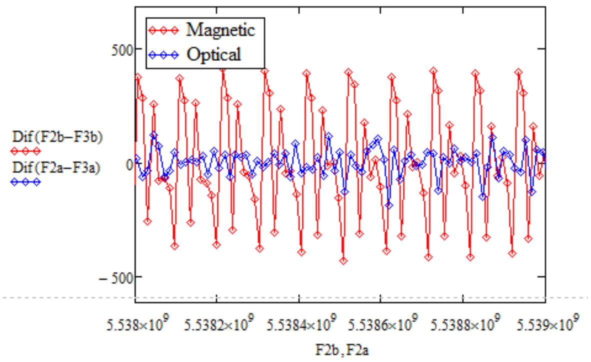


Fig. 64. Differential nonlinearity of pickup signals from magnetic and optical sensors.

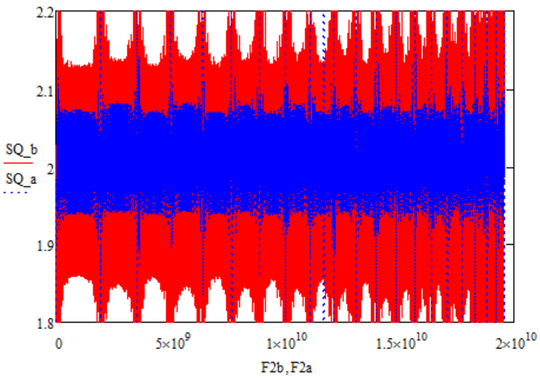


Fig. 65. Duty ratio of pickup signals from magnetic and optical sensors.

Detectors

Small-angle 45°- and 90°-detector systems based on 3He counters were manufactured and adjusted. These systems along with preamplifier units were installed on the RTD diffractometer and prepared for operation (Fig. 66).

Also, for the RTD diffractometer a design of a ring-shaped small-angle thermal-neutron-scattering detector was developed (**Fig. 67**). In contrast to the ring-shaped backscattering detector previously installed on RTD, the following modifications were made in the design of the small-angle detector:

- instead of stainless steel the housing is made of duralumin, which has significantly reduced its weight and the absorption of neutrons in the entrance window;
- method of fixing an anode wire was modified, which made it possible to reduce losses in the dead zones of the detector;
- all radii were made independent of each other, which allows the detector to be repaired without a complete disassembly;
- cylindrical cathodes are made of double-sided foil-clad fiberglass, which makes it possible to make 9 concentric counters instead of 8, as well as to divide the cathodes into 16 sectors and in this way to get one additional azimuthal coordinate.

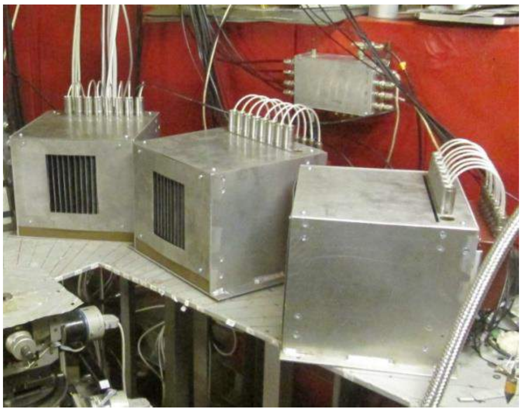


Fig. 66. Small-angle 45°- and 90°-detectors on IBR-2 beamline 6a.

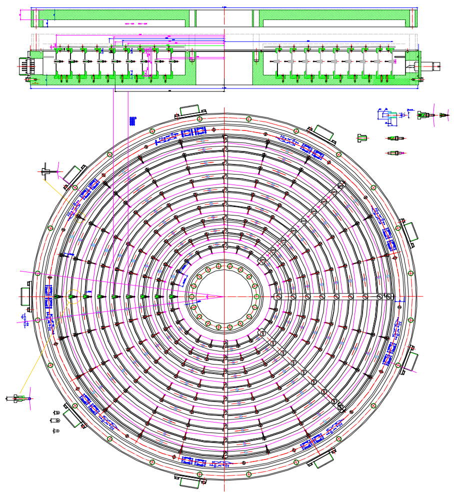


Fig. 67. Scheme of a small-angle ring-shaped detector of the RTD spectrometer.

The activities on completing the ASTRA detector system were continued. Within the framework of these activities the manufacturing of the plane comprising four scintillation counters was completed (3^d section, **Fig. 68**). These counters were installed on the FSD diffractometer and are being tested and adjusted in cooperation with the NICM Department. TOF spectra of both low (**Fig. 69**) and high (**Fig. 70**) resolution were obtained. In the framework of the preparation for tests a large amount of work was carried out on the adjustment of the MPD data acquisition and accumulation electronics adapted for the use with the ASTRA scintillation detectors.

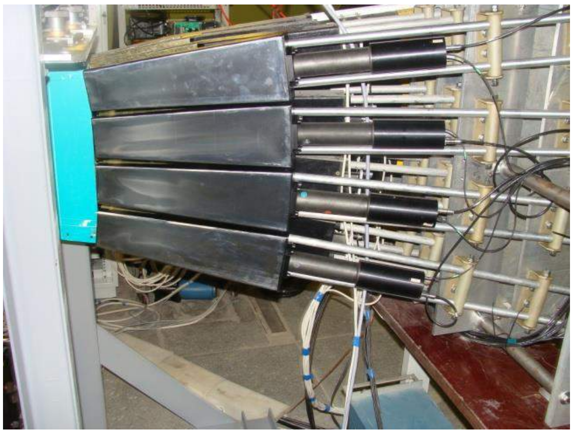


Fig. 68. Plane comprising four scintillation counters installed on the FSD diffractometer.

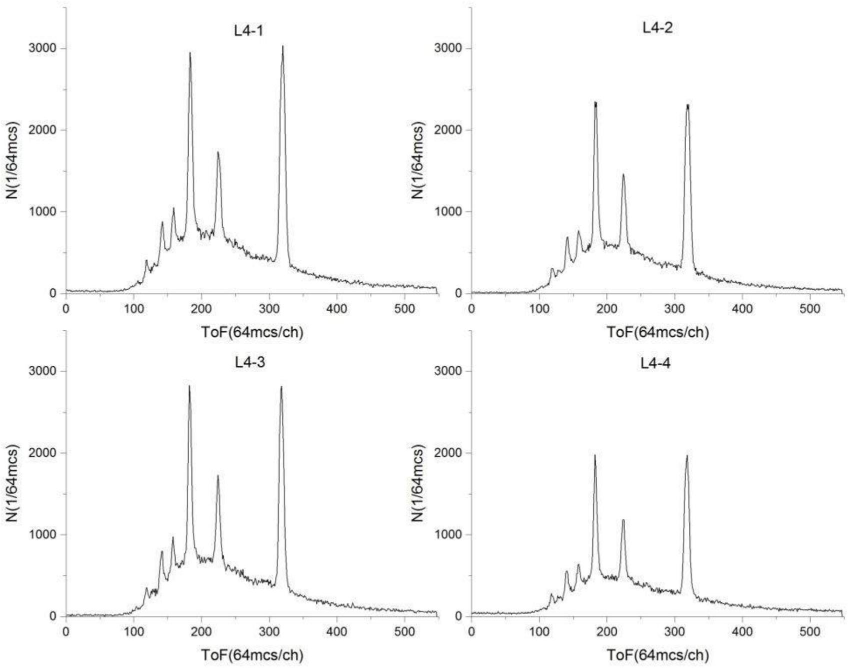


Fig. 69. TOF low-resolution spectra for four new counters.

A monitor 2D PSD was manufactured and prepared for testing. Its tests and in-service measurements of beam profiles are underway. The modernization of the PSD on the REMUR spectrometer has proved to be impossible without suspending experiments for a long time, therefore together with the physicists concerned it was decided to make a new detector. These works are included in the plan for 2015.

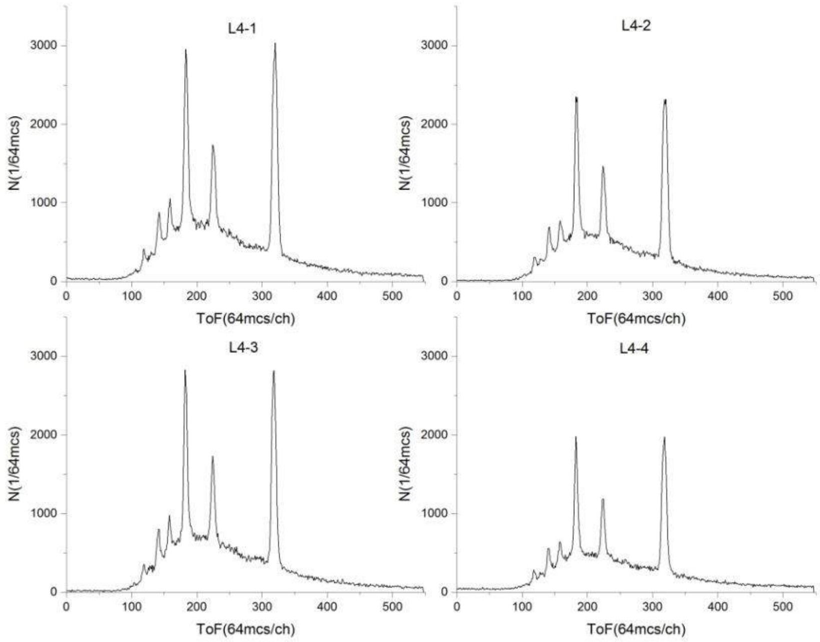


Fig. 70. TOF high-resolution spectra for four new counters.

Cryogenics

A shaft cryostat for a temperature range of 6-300 K was designed and put into operation on the NERA-PR spectrometer (**Fig. 71**). The cryostat uses a pulse tube cryocooler CRYOMECH PT405 and has a shaft 70 mm in diameter for inserting samples.

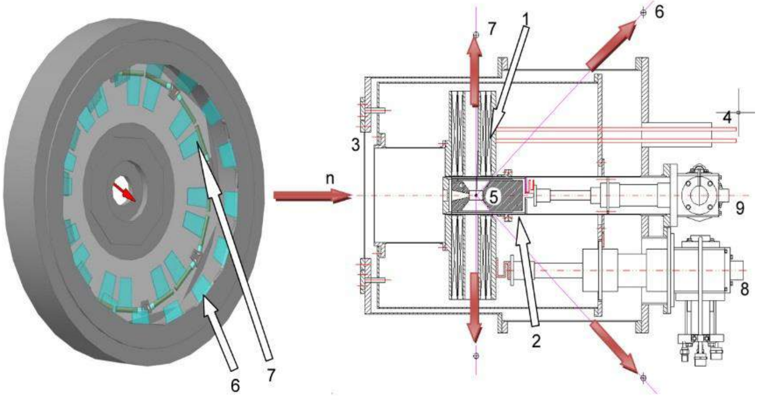


Fig. 71. Shaft cryostat for the NERA-PR spectrometer.

Fig. 72. Preliminary design of a cryostat with a superconducting magnet and cryostat-insert for the DN-12 diffractometer: 1 – superconducting magnet; 2 – cryostat-insert; 3 – entrance window for neutrons/window for backscattered neutrons; 4 – current lead (up to 300 A); 5 – high-pressure cell; 6 and 7 – detectors for neutrons scattered at angles of 45° and 90°; 8 – cryocooler RDK408S; 9 - cryocooler RDK101D.

The use of liquid helium and nitrogen in the conditions of a restricted access zone on DN-12 is limited for personnel safety reasons (the instrument is located in a confined space). For this reason and because of the geometrical layout of DN-12 units, obtaining low temperatures requires "cryogen-free" technologies – use of closed-cycle refrigerators without liquid cryoagents.

In order to simplify the cooling scheme of the magnet, and consequently its design, and to reduce the cost of its operation, it is considered advisable to use an HTSC tape as a superconductor of the magnet. A cooling temperature of 20 K is sufficient for operation of an HTSC-tape-based magnet and can be maintained by using liquid-helium-free cryocoolers (e.g., RDK408S).

Changing sample temperatures requires the development of a cryostat-insert for the magnet. This cryostat is planned to be equipped with holders and containers of high-pressure cells. High-pressure cells are to be made of non-magnetic materials.

Carrying out temperature measurements with the applied magnetic field requires the use of RDK101D cryocooler with a final temperature of ~ 3 K. The installation (**Fig. 72**) of the magnet on the DN-12 diffractometer will require the modernization of the housing of the diffractometer, as well as the inspection examination of the available equipment of the diffractometer in order to ensure its proper operation in magnetic fields.

Control systems of actuating mechanisms of IBR-2 spectrometers

The actuating mechanisms of the YuMO and REMUR spectrometers were upgraded and equipped with sensors. On the YuMO spectrometer, absolute multi-turn angle sensors were installed directly on the stepper motors (**Fig. 73**) for monitoring linear movement in the horizontal and vertical directions of the sample table and platforms of three detectors. The installation of sensors has , at the REMUR spectrometer an absolute multi-turn angle sensor monitors the position of the platform with a detector. At the Fourier diffractometer FSD a controller OSM88RA (current – up to 8 A, voltage – up to 72 V) was installed, thus allowing an order of magnitude (up to 1 mm/s) increase of the speed of the vertical movement of the Huber goniometer sample table.

A control system of actuating mechanisms with 4 control channels (with the possibility of further extension up to 32) was put into operation at the spectrometer of neutron radiography and tomography being constructed on IBR-2 beamline 14. The Huber goniometer head with three (two horizontal and one vertical) axes of rotation was connected to the system.

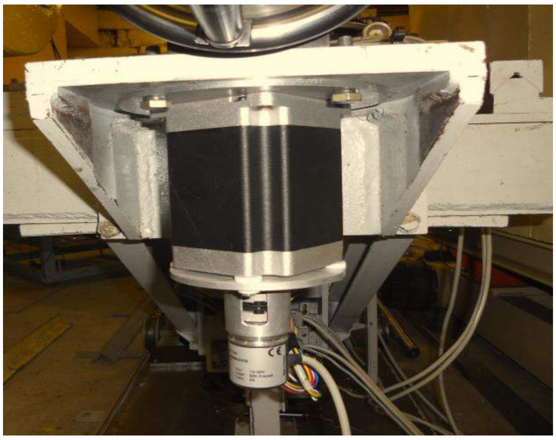


Fig. 73. Motor with angle sensor MSD1312 of the sample table for providing horizontal movement of samples at the YuMO spectrometer.

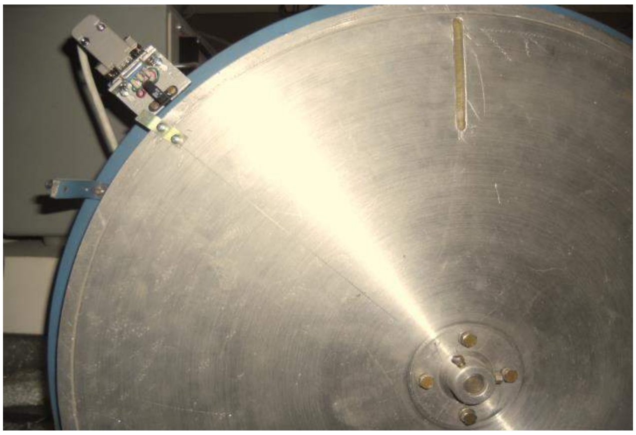


Fig. 74. Monochromator and control system on IBR-2 beamline 9.

Control systems of the chopper and the shutter were put into operation at the DN-6 and DN-12 diffractometers, and a DC-motor based monochromator (**Fig. 74**) with a magnetic speed sensor was put into -2 spectrometers' complex a new generation of unified data acquisition systems with world-class characteristics has been developed and constructed. These systems have been installed on all spectrometers. They are connected directly to PC and possess flexibility for fast adaptation to any changes in experimental conditions and to an increase in the number of spectrometer devices. The chosen architecture of DAQ-systems fits well into the network infrastructure and provides the ease and low cost of their regular modernization in accordance with the progress in computer engineering and communication technologies. An important distinction of this generation of electronics is the abandonment of nuclear electronics standards (CAMAC, VME, etc.), which reduce potentially achievable speed of operation because of the necessity to execute their internal protocols. Besides, the cost of "standard" electronic units is significantly higher because they, unlike computer devices and interfaces, are not mass products. The rejection of the VME standard allowed a change-over from the outdated and user-unfriendly OS-9 to the operating system Windows for the software package Sonix. And finally, new DAQ systems make it possible to accumulate raw data, which in some cases is of principal importance.

Data acquisition systems of practically all IBR-2 spectrometers consist of 1-2 basic modules, one of which processes and accumulates data from one- and two-dimensional PSD (De-Li-DAQ), and another – from an array of point detectors (MPD). From the viewpoint of hardware the basic modules are identical; and the specifying of all parameters, modes and operation algorithms specific to a concrete spectrometer, is realized on the level of microprograms, which are stored and executed in FPGA of the respective module under PC control.

An MPD module is used to acquire and store data from gas and scintillation counters. At present, all IBR-2 spectrometers are equipped with new DAQ electronics. All the above-mentioned DAQ systems consist of two types of units – one digital unit (its architecture is shown in **Fig. 75**) capable of registering and storing data from 1 to 240 point detector elements and several 32-channel analog units in which data acquisition, discrimination, transformation and transfer are performed from the detectors' preamplifiers to a digital unit MPD. In the analog unit the transition from LEMO connectors to a flat cable is done as well.

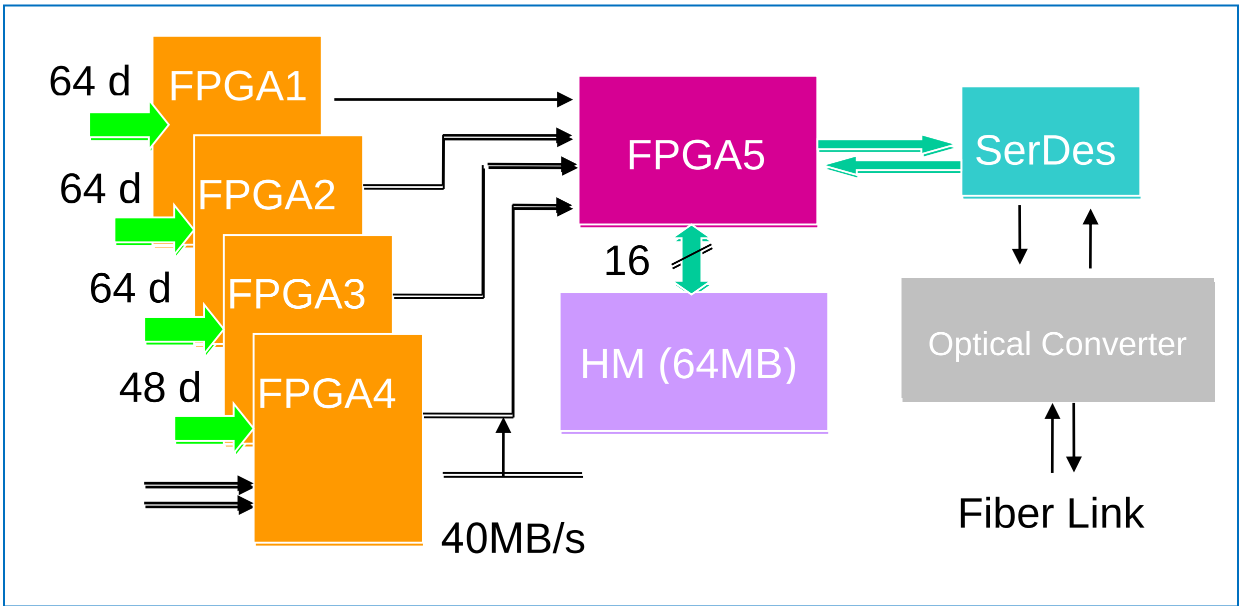


Fig. 75. Architecture of an MPD module.

These modules are also used for storing a set of histograms in short time intervals for real-time studies of transition processes in condensed matter (DN-2/RTD diffractometer).

For Fourier diffractometers HRFD and FSD a "list-mode" analyzer with a specialized software package (designed in the SC Department) has been developed and constructed on the basis of MPD modules. On these diffractometers first experiments were conducted with comparative simultaneous measurement of diffraction spectra using the existing DSP-based analyzer and the new list-mode analyzer. Using the developed algorithm high-resolution spectra were extracted from the list-mode data and compared with the DSP-spectra. The comparison has shown that the spectra are identical, which is indicative of the correct operation of the new electronics and the developed algorithms for obtaining diffraction spectra from "raw" data (for details see Section 1.1.2 of the Report).

Two types of unified new-generation electronic modules De-Li-DAQ-1 and De-Li-DAQ-2 have been designed for data acquisition and accumulation from one- and two-dimensional MWPC detectors with delay-line data readout.

The De-Li-DAQ-1 module has been developed in cooperation with HZB, Berlin. It is based on digital signal processors and field-programmable gate arrays, which has made it possible to realize wide functional possibilities and rather complex algorithms of selection and preliminary processing of events. The module has an inner histogram memory of 256 Mb and a count rate of up to 10^5 events/s. By now about fifty DAQ modules have been produced, which along with PSD developed in FLNP are used on IBR-2 spectrometers, in NRI (Řež, Czech Republic) and in a number of the Russian neutron centers (IMP UB RAS, Yekaterinburg, RRC "Kurchatov Institute", Moscow and Branch of KIPC, Obninsk) as well as in HZB, Berlin, with detectors of other producers. The module is installed in a free slot of a personal computer, connected to PC via a PCI interface and runs under OS Windows.

The new module De-Li-DAQ-2 has 1 Gbyte histogram memory, which makes it possible to accumulate three-dimensional spectra X-Y-TOF of up to 512×512×1024 32-bit words; and high-speed interface with optical communication link to a personal computer. Connection to a PC is via USB 2.0. The De-Li-DAQ-2 module provides a count rate of more than 10^6 events/s.

As is the case with MPD, both De-Li-DAQ modules provide data acquisition and accumulation in two main modes: histogram mode (on-line sorting and accumulation of spectra in the module memory), and list mode (when raw data are accumulated directly on a PC hard disk).

It should be noted that the above-described DAQ modules are only a part of data acquisition electronics with which our physicists deal with directly. In the reporting period nearly half of analog electronics, which, as a rule, are "hidden" from them, have been modernized. These are preamplifiers, shapers, discriminators, power supplies, cables, connectors, etc. for several hundred measuring channels.

The control systems of all IBR-2 spectrometers were modernized with the replacement of the control computer in the VME standard with a PC. Along with it, the control software package Sonix used earlier was replaced with Sonix+ adapted to a new set of equipment of the IBR-2 spectrometers that had been changed during the modernization (new detectors, actuating mechanisms, sample environment systems, digital electronics, etc.).

In the course of carrying out this work the possibilities of the software package Sonix+ were significantly extended:

- New modules for controlling all controllers developed in FLNP (MPD, De-Li-DAQ-2) or purchased (to control stepper engines, goniometers, loading devices, heaters, refrigerators, high-voltage power supplies, etc.) were added. For DAQ controllers in addition to the histogram mode, the mode of raw data accumulation was implemented.
- A new, simpler and more convenient universal graphical user interface (GUI) on the basis of PyQt and matplotlib was developed and introduced, which provides both the control of the

experiment and visualization of data from all detectors being used (point detectors, 1D and 2D PSD).

- A general approach to the creation of adjustment programs for the spectrometers was proposed. On the basis of this approach the programs were developed and introduced on the IBR-2 reflectometers (REMUR, REFLEX, GRAINS) and spectrometers (YuMO, EPSILON) (**Fig. 76**). One of the versions of the program is used on the DN-6 and DN-12 spectrometers as a user interface for experiment control.
- An approach to the creation of programs for keeping a measurement log was proposed. The first variant was created and is successfully used on the YuMO spectrometer.
- A change-over of all Sonix+ components to Microsoft Visual Studio 2008 and Python 2.6 was made.

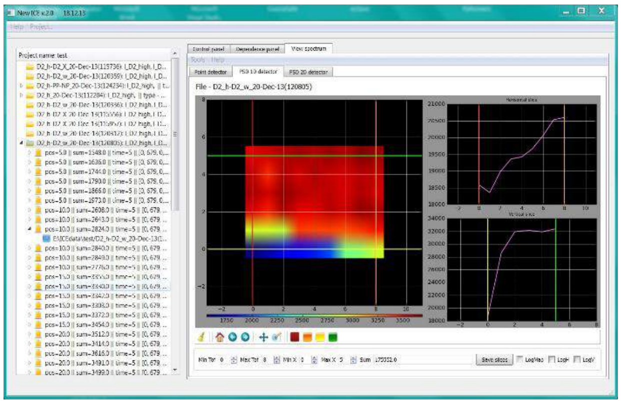


Fig. 76. Adjustment program: visualization of two-dimensional scanning data at the REMUR spectrometer.

Taking into consideration the operational experience and users' feedback, the remote experiment control system WebSonix was radically redesigned. The main results of the modernization are the improvement of the user interface, as well as higher reliability and security of the system due to the use of the latest web technologies. The help section of the system in Russian and English was significantly supplemented. A cold moderator monitoring software has been upgraded.

A regular operation of the FLNP central file-server Supermicro 6047 was started. A number of teams of physicists came up with a proposal for using it as a basis for organization of a centralized fault-free network-attached storage system for data measured on the IBR-2 spectrometers. This approach provides:

- automatic transfer of experimental data;
- continuous availability of data;
- data backup in case of a hard disk failure on the host computer of a spectrometer;
- regulation of data access rights on the server.

All services of the server are configured as a single system, which organizes network-attached storage and ensures its operation. The sftp and samba protocols allowing for the encryption of users' password have been selected to provide access to the data.

A number of requirements were put forward to the script for writing data to the server. The implementation of these requirements ensures the reliability and safety of the data storage system:

- script should be integrated into the general system for controlling experiments Sonix+;
- when writing data to the server it should copy the structure of experimental data on the host computer of the spectrometer, as well as record intermediate files if they are changed during the experiment;

- script should be maximally isolated from the general system;
- a detailed log of all processes occurring while writing data to the server should be kept in the system.

The first version was tested during a number of the reactor measurement cycles at the FSD, HRFD and SKAT spectrometers. Particular attention was paid to providing uninterrupted measurements in case of possible failures in data transfer to the server. On the whole, the tests have shown sufficient reliability of the system. In the future it is planned to provide authorization of users of the data storage system via the FLNP general authorization system, as well as to develop additional services for the convenience of working with the data storage system.

The technical specifications of the server are given in the Annual Report for 2013. An SAS2108 RAID controller and eight 4 GB RAM units, which are used as a cache, were purchased and installed in addition to the initial configuration of the server. The total usable storage capacity is 58 TB.

A new Supermicro SYS-6017R-TDAF server with two CPU Intel Xeon, 16 TB disk space and operating system Linux got its first active users.

The main tasks in the development of the FLNP network have been fulfilled (Fig. 77):

- An upgrade of the FLNP backbone network to a 10 Gbit/s rate has been done.
- The rate of up to 1 Gb/s has been provided for the end-users in the main network segments;
- The creation of a WiFi network has been completed in the FLNP main buildings and the IBR-2 experimental halls;

A trouble-free operation of all network equipment has been maintained both on the IBR-2M spectrometers and in the offices of the Laboratory.

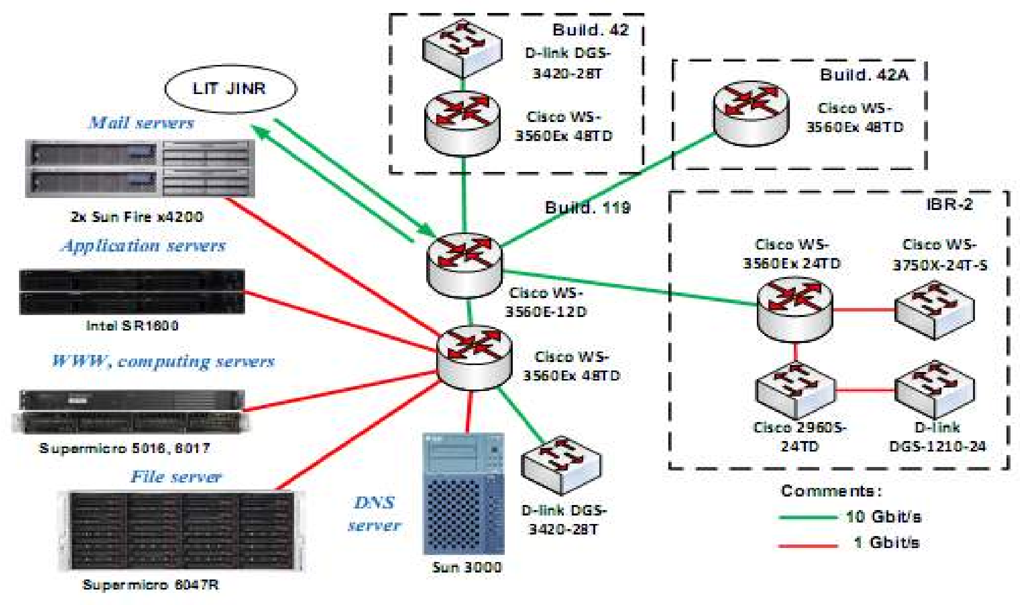


Fig. 77. Logic diagram of FLNP network (2014).