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Development and Modernization of the System for the Diagnostics of the State of the Pulsed Neutron Source IBR-2

Pepyolyshev Yu.N., Belushkin A.V., Vinogradov A.V.
Frank Laboratory of Neutron Physics (FLNP), Joint Institute
for Nuclear Research (JINR),
141980 Dubna, Moscow Region, Russia

The fast neutron reactor of periodic operation IBR-2 generates neutron pulses with the frequency 5 Hz and the average power 2 MW /1/. The reactor is characterized by a high sensitivity to reactivity fluctuations and the existence of a massive mechanical structure, the reactivity modulator (RM), which rotates close to the reactor core and essentially influences neutron pulse fluctuations. An increase in the sensitivity is of fundamental character. This is caused by several reasons. First, when the reactor operates in the pulsed mode its sensitivity to reactivity fluctuations sharply increases. Second, energy fluctuations of power pulses increase significantly compared to steady-state reactors because of additional sources of reactivity fluctuations such as, for example, vibrations of the RM blades. In the pulsed mode as compared to the steady-state mode of operation (without rotation of RM), the main characteristics of the reactor change significantly. For example, the kinetic, dynamic and thermodynamic characteristics of the reactor vary. Thus, when controlling the state of the pulsed reactor, in addition to the usual requirements the control over the change in the noises of the reactor and vibrations of RM, as well as over the change in dynamic characteristics of the reactor core, which influence the instability /2/, should be exerted

Therefore, to carry out the diagnostics of the IBR-2 state in investigations during physical and energy startups and in the process of the exploitation of the reactor, the methods of noise diagnostics are used. The main stages of reactor investigations where the methods of noise diagnostics are widely used include.

1977 – 1984	The IBR-2 reactor physical and energy startups. Experimental investigations of the reactor. The main studies in that period were aimed at determining and optimization of the performance characteristics and improving the quality of the reactor as a pulsed neutron source.
1984 – 1997	Exploitation of the reactor. Investigations and monitoring of the principal reactor parameters. Experimental substantiation of a reliable and safe mode of the reactor operation.
1997 – 2000	Creation of a new information and diagnostics system for the reactor users.

The main elements of IBR-2 whose states are analyzed by the methods of noise diagnostics are:

1. Reactor core. Energy fluctuations of neutron pulses. Analysis of the fast neutron pulse shape.
2. The first contour of the sodium cooling system. Fluctuations of the inlet and outlet temperatures of the cooling agent. Fluctuations of the cooling agent expenditure in two loops of the first contour of the cooling system of the reactor core.
3. Reactivity modulator as a complex rotational machine. Axial vibrations of the blades of the main and auxiliary movable reflectors. Vibrations and displacements of supports for the shaft of the main movable reflector.

To analyze time series, the methods of spectral and correlation analysis, image identification, multidimensional data compression for visualization of the data are accepted. At present, the new updated system for the examination and diagnostics of IBR-2 is being created. The general state of the reactor will be analyzed on the basis of a total of 40 measured reactor parameters.

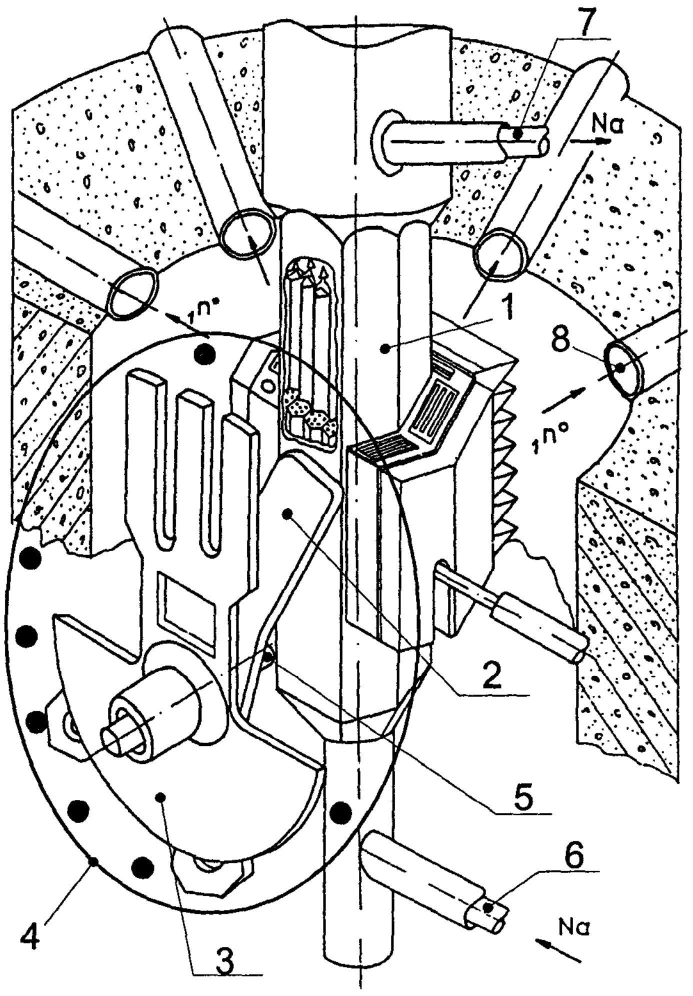

Fig. 1. The principal scheme of the IBR-2 reactor and positioning of sensors: 1 – reactor vessel, 2 – main movable reflector (MMR), 3 – auxiliary movable reflector (AMR), 4 – RM jacket with 16 sensors of MMR and AMR blade positions, 5 – vibration pickups and AMR front support displacement pickups, 6 – sodium temperature sensor in the inlet collector, 7 – sodium temperature sensor in the outlet collector, 8 - neutron flux detectors (fission ionization chambers).

Regular measurements of dynamic characteristics of the reactor using controlled single or repeated changes of the reactivity will complement noise diagnostics. Important is that the new system gives access for neutron beam users to part of the information in the close to real time mode through FLNP net servers. Work to develop a system with advanced hardware and software using modern computing means is now in progress at the IBR-2 reactor. The main functions of the system are as follows:

1. Availability of operative information for neutron users and the reactor staff;
2. Measuring of not less than 40 principal reactor parameters with a frequency equal to the pulse repetition rate 5 Hz during each two-week reactor cycle;
3. Preliminary noise diagnostics. Data processing in the real-time mode. Creation of a data base;
4. Processing over full data (over all reactor cycles) in the close to real time mode to search for anomalies and compute trends;
5. Possibility of performing additional investigations of the reactor (dynamic characteristics);
6. Evaluation of the vibration state of the reactivity modulator as a complicated rotating machine;
7. Fast neutron pulse shape measurements. Operative evaluation of kinetic parameters.

The system is oriented for powerful PC-class machines and the FLNP net server as shown in fig. 2.

Access to data is realized via user passwords automatically defining the necessary data volume for a particular user from any machine with the net support. A distributed automatic system for IBR-2 users with generation of a Web page on the FLNP net server has existed in FLNP since November 1996 and is the prototype of one of the components of the discussed system. In particular, it is possible to have current information about the reactor power and the state of a neutron guide (open-closed) together with some other information from the following address:

http://nfdnf.jinr.ru/flnph/ibr-2/cycles/ibr2_monitoring.html

Information is updated every 10 minutes of the reactor operation.

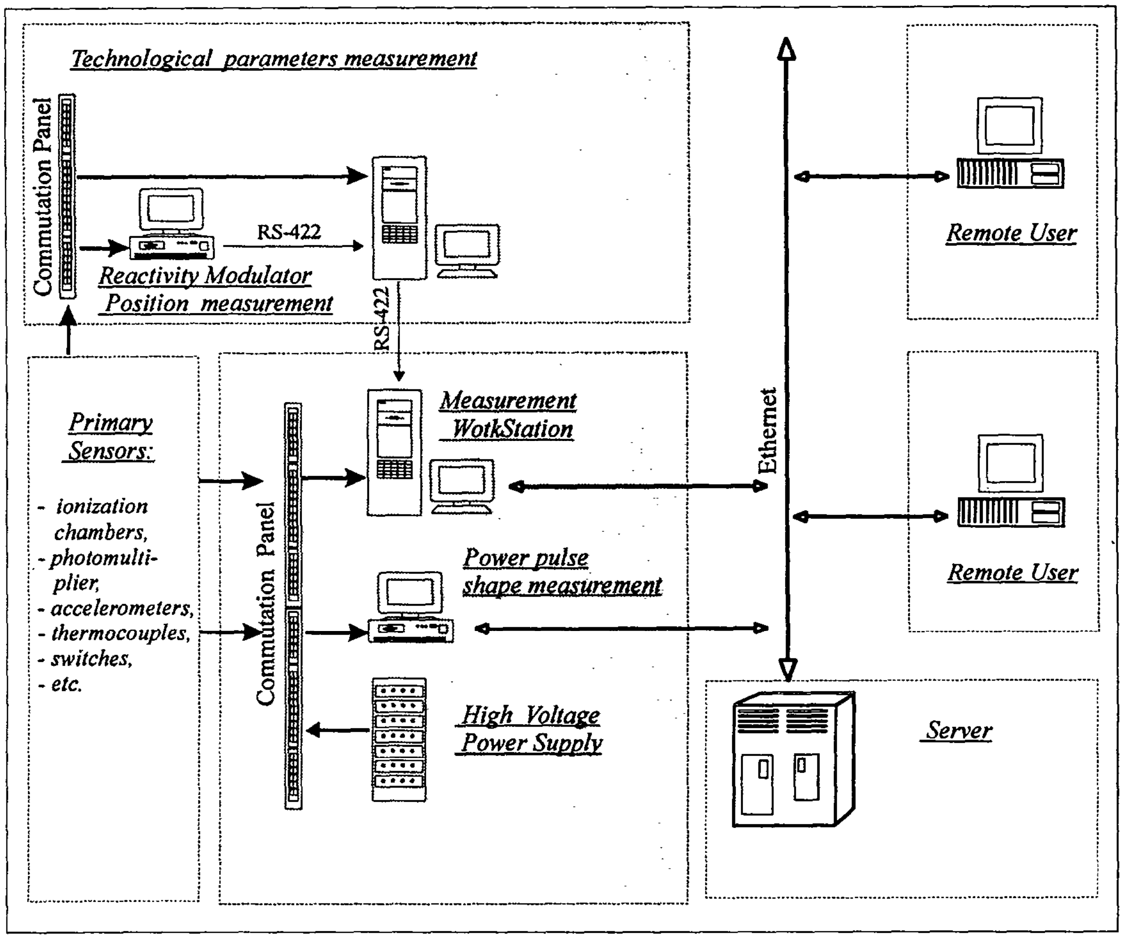

Fig.2. The scheme of the diagnostics system.

Following are some experimental results obtained in the operation of the IBR-2 reactor. Under any change of the mean power or the coolant flow rate through the reactor core the character of power fluctuations (spectrum shape and absolute deviations) changes. As an illustration, Fig.3 shows relative changes of pulse energy fluctuations as the power decreases from 1.8 to 0.82 MW.

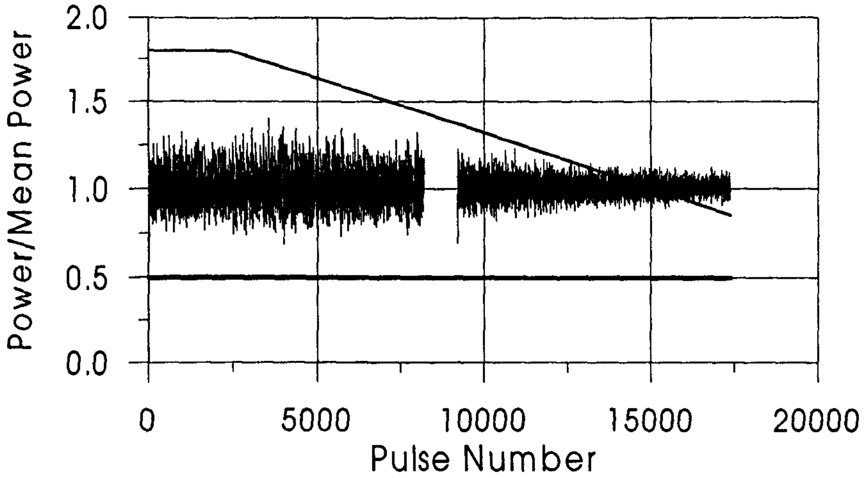

Fig.3. Changes in relative power noises as the power was decreased from 1.8 to 0.82 MW for the coolant flow rate 80 m^3/h .The upper curve shows the power (MW). At 0.5 the lower limit for the reactor shutdown is marked. On the abscissa the number of registered power pulses is plotted. The total time of the cycle is one hour and three minutes. The break in the pattern is connected with an interruption in the measurements.

Some partial components of the spectrum density of pulse energy fluctuations depend on the power and the coolant flow rate in a different manner. The absolute deviations of pulse energy fluctuations in the low frequency region are shown in fig. 4. As is seen in figs. 3,4 the dependence of pulse energy fluctuations on the mean power and the coolant flow rate has a complex character. For example, in the region from 1.5 to 1.8 MW, low frequency oscillations sharply increase and their amplitude essentially depends on the coolant flow rate.

The second important task of the control over the state of the pulsed reactor consists, as mentioned above, in determining current dynamic characteristics of the reactor. It is well known that while the reactor is in operation, neutron-physical, thermohydraulic and mechanical characteristics of the reactor core change. The changes can be due to natural processes connected with the burn of fuel elements or changes in the core due to reloading or replacement with fresh ones of fuel elements leading to changing of dynamic characteristics of the reactor. For example, the important characteristics of the reactor, such as the power reactivity coefficient or its separate components, alter. Knowledge of the current characteristics of the power feedback is necessary for estimating the behaviour of the reactor in various transitions and emergencies. It is especially important for a pulsed reactor since it has some limiting power above which it becomes unstable. The value of the limiting power depends on fast components of the power feedback. Therefore, a monitoring system for fast components of the feedback using the rectangular reactivity oscillations method is created at the IBR-2 reactor. The data obtained in the operation of the system during the period from 1989 to present is used to analyse the physical nature of changes occurring in the core and, also, to substantiate a reliable and safe mode of operation of the reactor.

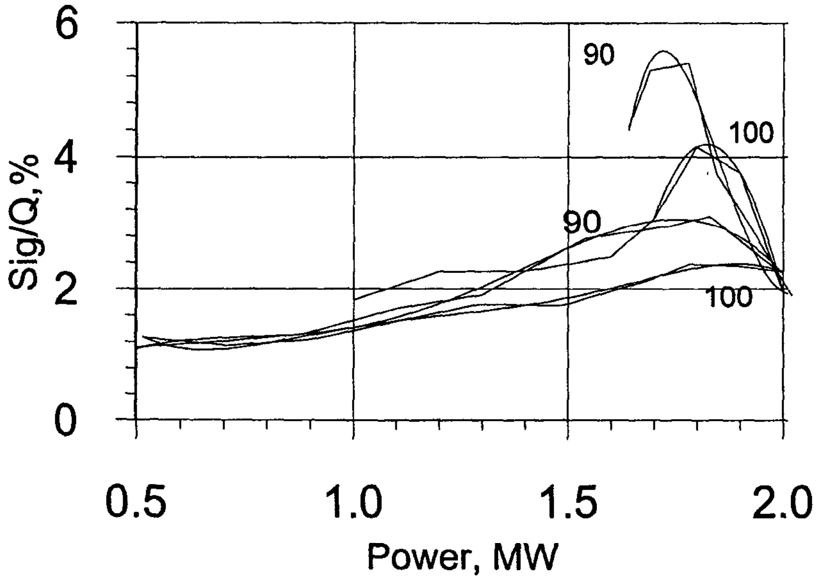

Fig.4. Changes in mean square root deviations of the energy of power pulses in the low-frequency region of the spectrum (0.01-0.4 Hz) as the power increases up to 2 MW and decreases from 2 MW at the sodium flow rate 90 and 100 m^3/h in contour I. Two upper curves were measured as the power decreased.

In the stable pulsed mode of reactor operation, a periodically varied reactivity of "meander" type is introduced into the reactor. An acute reactivity change is realised between power pulses (in less than 0.2 s). For periodic changes of external reactivity, stationary oscillations of the deterministic oscillations of pulse energy with imposed statistical power fluctuations are established. Identification of the deterministic component is only possible by smoothing measurements over many periods because of large power fluctuations ($\sigma q/Q = 8\%$). As an example, the measured deterministic component of power oscillations averaged over four hours is presented in Fig.5. The 1989 to 1997 experience with the power feedback characteristics (PFC) monitoring system for the average Pu-239 burn from 1 to 4% shows that PFC of the IBR-2 reactor depends on the coolant flow rate through the core and the mean reactor power /3/.

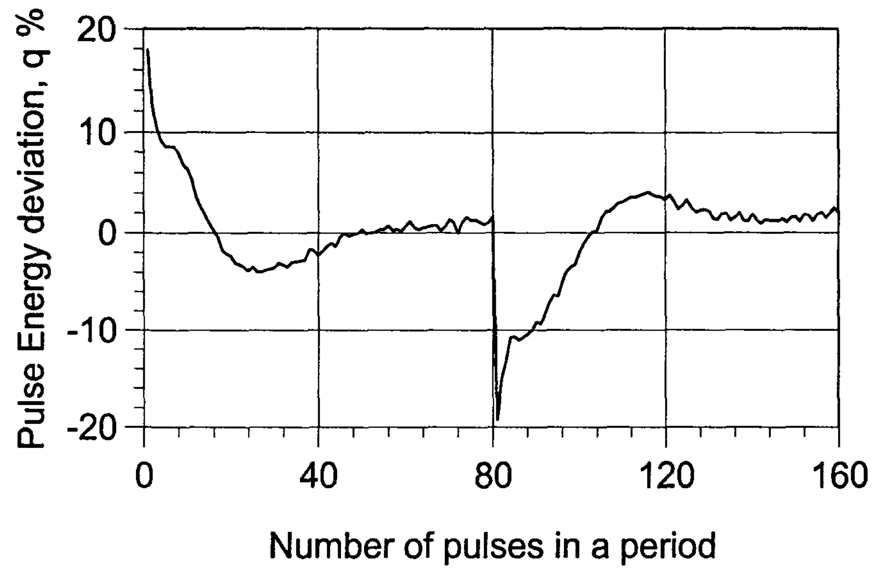

Fig.5. The defining component of power oscillations under external reactivity modulation with the repetition rate 160 reactor pulses. Averaging is performed over 600 periods. The amplitude of the modulating reactivity is $8\cdot10^{-6}$ ΔK/K. On the ordinate axis, pulse energy deviations from the mean value are shown.

The presented report outlines only part of problems connected with the research and diagnostics of the IBR-2 reactor. It is apparent that the task of the diagnostics of the reactor is much broader than it has been discussed. We hope that in connection with the development of pulsed neutron sources in different countries there will be a good chance for joint effort in the field of diagnostics and increasing the safety of the existing and future pulsed neutron sources.

References

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