Development of a mathematical model of pulsed fast reactor dynamics: results and prospects

M. V. Bulavin

Frank Laboratory of Neutron Physics, Joint Institute for Nuclear Research, 141980, Dubna, Russia
bulavinnm@nf.jinr.ru

The primary characteristic of a pulsed nuclear reactor that affects its stable and safe operation is oscillatory instability, determined by the magnitude of pulse energy fluctuations.

Thus far, the acceptable limits of pulse energy fluctuations for the pulsed reactors IBR-2 and IBR-2M have been established experimentally. However, any alternative core configuration for a new reactor with increased power and intensity necessitates rigorous justification to ensure its nuclear safety.

Consequently, a critical objective in the development of a new pulsed reactor at JINR is the theoretical characterization of the processes underlying pulse energy fluctuations, as well as the comprehensive study of the mechanisms driving power feedback through the application of a mathematical model.

Recently, significant progress has been achieved in the development of a mathematical model for reactor dynamics under the short-pulse and low-background approximation. This model is aimed at addressing the following challenges associated with the instability of pulsed reactors:

- Investigation of the causes of instability;
- Determination of the parameters for stable operation;
- Development of an optimal core design;
- Validation of theoretical approaches to studying reactor dynamics.

The model represents a computational program with a modular structure, designed to simulate the dynamics of a pulsed reactor by incorporating key parameters, such as pulsation frequency, average reactor power, decay time of transverse oscillations of fuel elements, their mass differences, transverse and thermal reactivity parameters, the pulse transient response characteristics in the power feedback model, and others. It also integrates boundary conditions and computational methodologies for analysis.

Setting boundary conditions involves selecting the method of fixation for an individual fuel rod (or fuel assembly). Based on this choice, the program applies a specific set of eigenvalues and eigenfunctions when solving the equations of motion. Selecting the calculation method refers to choosing the approach for determining reactivity ρ during the next power pulse.

The core loop of the program is a closed iterative cycle, wherein the energy of the next pulse Q_i, is determined based on the energies of preceding pulses. The central component of this process is the kinetics module, which solves the neutron kinetics equations using the specified reactivity, the energies of previous pulses, and the modulator velocity (parameter ν). This module computes the sources of delayed neutrons and determines the energy of the subsequent pulse.

The reactivity value input to the kinetics module is calculated as the sum of individual reactivity components, each corresponding to a specific factor (physical process) affecting the reactor's reactivity: the automatic controller, external perturbations, thermal expansion, thermoelasticity (transverse deformations), and the influence of the coolant – each associated with a specific program module. The last three factors correspond to feedback mechanisms.

Calculations using this model indicate that exceeding the stability limits of a pulsed reactor may be caused by at least two factors: thermal expansion of the fuel and dynamic bending of fuel rods or bending of fuel assemblies during a pulse. Consequently, the following methods for reducing oscillatory instability in pulsed reactors are proposed:

- Determining the boundary of the stochastic instability region to select the optimal reactor frequency and power.
- Optimizing the reactor core design based on the natural frequencies of transverse vibrations and the reactor's operating frequency.
- Evaluation of the friction magnitude for transverse vibrations.
- Utilizing fuel rods (or assemblies) with varying masses or stiffness.

Taking into account the effects of coolant flow in the core, the design of fuel assemblies, and the precise temperature distribution will allow for the proposal of additional methods to enhance reactor stability in the future. Furthermore, the inclusion of the power feedback block (PF) in the program, as well as the analysis of calculation results in the form of the pulse response characteristic, expands the possibilities for studying the dynamics of pulsed reactors. This enables comparative calculations using different models, including those based on numerous results from the study of the dynamics of the IBR-2/IBR-2M reactors.