Results of a study of nonstationary processes in the I. V. Kurchatov Beloyarsk Atomic-Power Station, using an electrical analog machine together with the actually-operating control apparatus, are presented. This enabled the dynamic characteristics of the power unit to be obtained and the optimum parameters for setting the main controls of the station to be selected.

The theoretical characteristics of the reactor were also compared with experimental results measured directly.

The I. V. Kurchatov Beloyarsk Atomic-Power Station (BAPS) is the first industrial atomic-power station in the world to use nuclear superheating of steam [1, 2]. The nominal and transitional operating conditions of the station constitute a complicated mass of neutron-physical and thermophysical processes in a complex technological scheme.

Under certain conditions, perturbation in the reactor and turbine may produce an abnormal deviation of the technological parameters and lead to emergencies, costly equipment being put out of action. Thus on increasing the power there may be a crisis of boiling in the evaporation channels, leading to their overheating. Surges of the level in the evaporators may be accompanied by spattering of nonseparated drops of water in the steam-superheating channels.

Experience gained in using present industrial plants did not indicate any dynamic laws for the system under consideration or determine the conditions for the accident-free operation of the BAPS system. Hence the problem was attacked by a mathematical modeling method. The physical principles of the mathematical model for the nonstationary thermal processes taking place in the technological system were verified experimentally on a thermal testing unit with the fundamental technological arrangements of the BAPS [3].

The investigations enabled us to substantiate the general assumptions made and to determine the limits within which theoretical results agreed closely with experimental. This enabled us to choose a reasonable mathematical model of the BAPS and study this over a relatively wide range of parameters.

The nonstationary thermophysical processes were described by a system of differential equations, which, on the assumptions generally made (as formulated in [3]), reflected the laws of the conservation of energy, mass, and momentum, and the heat-conduction equation. The neutron-physical processes were described by kinetic differential equations, using six groups of delayed neutrons, allowing for density and temperature changes in the heat carrier, uranium, and graphite.

The inhomogeneity of the distribution of heat carrier and thermal flux over the radius of the active zone in the reactor meant that, depending on the geometrical position, the heat-emitting elements had different dynamic characteristics. The inertia of the fuel elements rises from the center of the active zone to the periphery. This can easily be shown; in the first approximation (or more exactly for hollow cylindrical fuel elements with a ratio of internal to external diameter close to unity) the time constant of heat transfer from the wall of the fuel element to the heat carrier is determined by the equation

\[ t^* = \frac{C_m M_M}{\alpha_p} \text{ sec,} \]
where \( C_M \) is the specific heat of the metal of the fuel element in kcal/kg·deg, \( M_M \) is the mass of metal in the fuel element per unit length in kg/m, \( \alpha \) is the heat-transfer coefficient in kcal/m²·h·deg, \( p \) the perimeter of the fuel element in contact with the heat carrier in m. The coefficient \( \alpha \) is functionally connected with the mass flow of heat carrier \( G \) (kg/h) and the specific heat flux \( q \) (kcal/m²·h); for single-phase sections \( \alpha \sim G^{0.8} \), for two-phase \( \alpha \sim q^{1.7} \).

If at some point of the active zone in the reactor there is a local change in the temperature of the fuel or moderator, then the density of thermal neutrons in the reactor also changes, this change depending on the geometrical position of the point in question. The effect of this perturbation on the critical condition of the reactor is determined to a first approximation by the distribution of neutron density over the reactor before the introduction of the perturbation.

For large homogeneous reactors the effect of a perturbation \( \Delta k \) a long way from the boundary of the active zone with a reflector is proportional to the square of the unperturbed neutron density \( \Phi_0 \) in the region of perturbation:

\[
\frac{\Delta k}{k} \sim \left( \int \frac{\Phi_0 \, dw}{\sqrt{\int \Phi_0 \, dw}} \right)^2
\]

Thus each group of channels situated on a circle of the \( i \)-th radius \( r_i \) will be characterized by its own time constant \( \tau_{r_i} \) and gain factor \( C_{r_i} \), which, characterizing the "value" of the neutron-density distribution, is determined by the relation

\[
C_{r_i} \sim \frac{\Phi_{r_i}^2}{\Phi_{a,z}^2},
\]

where \( \Phi_{r_i} \) and \( \Phi_{a,z} \) are the density of thermal neutrons at the point \( r_i \) and the average value of the neutron density over the whole active zone. Hence in the transitional process the temperature feedback may be represented by an infinite series of parallel inertia elements with their own time constants and gain factors. The greatest contribution, both with respect to rapidity of action and amplitude, is introduced by the central group of channels.

In order to realize this on the "Baikal" analog machine, the system of differential equations was linearized and, by using Laplace transformations, reduced to a system of parametric transcendental intermediary functions, and then approximated by a system of fractional-rational polynomials.

The automatic control system of the steam-producing equipment in the BAPS provides for maintaining the main technological parameters at a given level for operation in either the base or peak condition. Let us consider the automatic control systems for the reactor power and thermophysical parameters.

The reactor-power control system ensures automatic variation of the power and maintains it in conformity with the load on the power-station generator, also compensating changes in the reactivity caused by burn-up, poisoning, thermal effects, etc.

This system is also furnished with three independent automatic regulators operating in a range equal to 4 to 125% of the nominal power. Considering the large dimensions of the reactor and the inadmissibility of misalignments of heat evolution in the active zone, automatic control of the reactor power is effected by two rods disposed symmetrically with respect to the vertical axis of the system.

The automatic regulator is astatic, ensuring proportional control. Each automatic regulator receives a signal from an ionization chamber proportional to the actual average reactor power and a signal from a power controller. The error signal, proportional to the difference between the actual and assigned powers, is fed to the general automatic-control tract and then to two executive mechanisms. Each executive mechanism uses a two-phase asynchronous motor to move one of the rods. The maximum rod velocity for automatic control and a power deviation of 10% is 0.35 m/sec. The compensating factor of the rod belonging to one regulator equals 3.6·10⁻³.

The automatic-control system for the thermophysical parameters of the station consists of primary measuring devices designed for operation with induction elements, thermocouples and resistance thermometers, electrical executive mechanisms, etc.