THE USE OF MNB-1 TYPE ANALOG COMPUTERS FOR SOLVING NUCLEAR POWER PROBLEMS

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Inzhenerno-fizicheskii zhurnal, Vol. 8, No. 1, pp. 110-115

The possibility of using MNB-1 and MNB-7 computers with special attachments to investigate the dynamics of nuclear power systems is examined.

Analog computers are finding wide application in relation to planning and research problems, especially those concerning automatic control systems. Though inferior in accuracy to digital computers, analog computers (AC) offer a rapid and convenient picture of the investigated process with an accuracy sufficient for practical purposes. The error of solution on an AC does not exceed 10%, and depends to a large extent on the nature of the system of differential equations being modeled. The use of an AC is fully justified in cases when the input data describing some system or other are known to an accuracy commensurate with the solution.

Commercial AC's of the MNB-1 type have been used successfully to investigate the dynamics of nuclear power systems. The MNB-1 permits the solution of a nonlinear system of differential equations up to the 12th order, with nonlinearities up to 12 in number (4 multiplier units and 8 dependent-function units, of which 4 are based on electromechanical slave systems). There are, moreover, 4 units for reproducing relations of the "backlash" and "relay characteristic" type. The number of constant coefficients which can be set up separately to three figures is 32. The operational amplifiers have an autostabilized zero level, and consequently low output drift (not exceeding 15 to 20 mv per 100 sec in the integrating regime for RC-1). The amplifier frequency response as an inverter is linear to 1,000-1,100 cps. The integrating and summing accuracy is 0.5%, and 1 to 1.5% in nonlinear operations. Two MNB-1 machines may be operated in conjunction. The power supply is an electronically stabilized ECV-2m rectifier.

Since nuclear energy factors are described by high-order systems of differential equations, it is necessary to use several AC's in parallel, which is quite simply accomplished, even with machines of different types. Also, the resources available may be substantially augmented by using independent attachments, simulating individual elements of the system. In particular, it is desirable and convenient to have a simulator for the reactor itself [1, 2, 3, 6].

The variation of neutron density with time in a reactor in 6-group theory is described by the following equations:

$$\frac{dn}{dt}=\frac{\Delta kn}{l}-\frac{\beta n}{l}+\sum_{i=1}^{6}\lambda_i c_i,\quad \frac{dc_i}{dt}=-\lambda_i c_i+\frac{\beta_i n}{l}. \tag{1}$$

In a reactor with thermal neutrons from U^{235}, the only variable parameter in (1) is the quantity l. It is therefore expedient to simulate (1) with a system also containing a minimum number of variable parameters.

The authors used the scheme shown in Fig. 1, which is a variant of the simulator described in [6]. Although not optimized as regards number of operational amplifiers, this scheme is very convenient to use. The equations for c_i are simulated using both active elements – amplifiers Y_1-Y_4, and passive elements – circuits R_1C_1 and R_2C_2. The use of these circuits permits some reduction in the number of amplifiers in the system. The only variable parameters in the system are the resistors R_6, R_7, proportional respectively to $1/l$ and $M_{\Delta k}/l$. In some reactor kinetics simulator schemes with varying l, the capacity of the condenser has to be changed, which is less convenient than changing the resistor. Resistors R_3, R_4, R_5 form the usual scheme of setting initial conditions. The scales for c_i are so chosen as to set up initial conditions on amplifiers Y_1-Y_4 automatically, in accordance with $n(0)$. The derivative dn/dt may enter into the heat transfer equation. The simulator scheme given is convenient in that we have a voltage proportional to mdn/dt at the output of amplifier Y_6. Power is supplied to the circuit by an ECV-6 unit. The control system (not shown in Fig. 1) ensures operation in parallel with the MNB-1. The solution may be carried through either in real time or slowed down by a factor of 5, this being accomplished by connecting the auxiliary condensers C_1'-C_7' to condensers C_1-C_7, respectively.

An MNB-1 and reactor simulator were used to determine the stability of an installation with natural circulation of heat-transfer agent (water), including both positive and negative temperature feedback. Only the problem of stability of the reactor itself, without the control and power sections, was examined. A statement of the problem, the assumptions, and the derivation of the equations have been given in [7]. In the simplest case, omitting hydrodynamic and thermodynamic effects, the system of equations describing heat transfer in the reactor has the form

$$\frac{dx}{dt} = a_{11}x + a_{12}T_1 + a_{13}n;$$

$$\frac{dy}{dt} = a_{21}y + a_{22}x + a_{23}T_2 + a_{24}n;$$

$$\frac{dT_1}{dt} = a_{31}T_1 + a_{32}n + a_{33}\frac{dn}{dt}; \qquad (2)$$

$$\frac{dT_2}{dt} = a_{40}T_2 + a_{41}n + a_{42}\frac{dn}{dt};$$

$$\Delta k = \Delta k_{в} + a_{51}y + a_{52}x;$$

$$\frac{dn}{dt} = \frac{\Delta kn}{l} - \frac{\beta n}{l} + \sum_{i=1}^{6}\lambda_i c_i; \quad \frac{dc_i}{dt} = -\lambda_i c_i + \frac{\beta_i n}{l}.$$

To determine the stability of the system, amplitude-frequency and phase-frequency characteristics were plotted. The frequency characteristics of the reactor were plotted for various power levels by feeding in a reactivity perturbation $\Delta k_p = 10^{-4} \sin \omega t$ and measuring the oscillation amplitude and phase shift for a number of values of ω. From the results

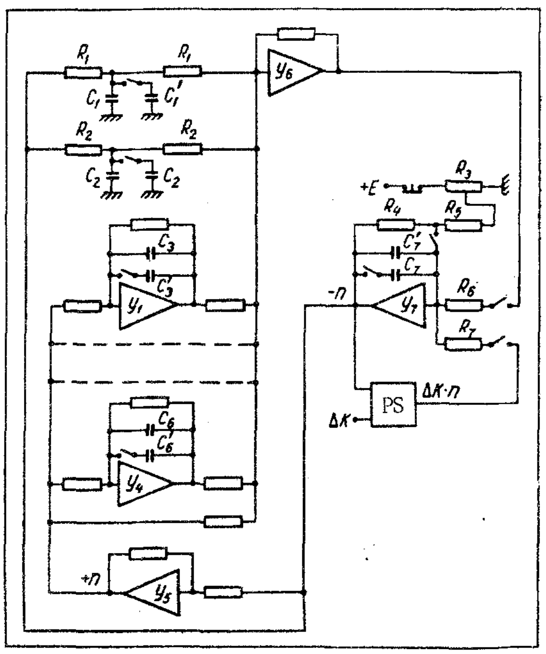

Fig. 1. Diagram of reactor simulator.

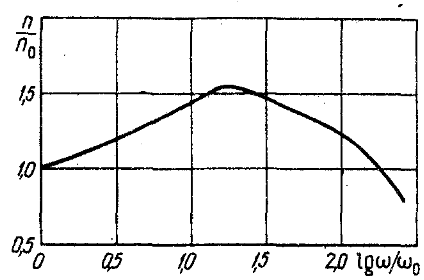

Fig. 2. Amplitude-frequency reactor characteristics with temperature feedback: $\Delta k_p = 10^{-4} \sin \omega t$, $\omega_0 = 1.256 \text{ sec}^{-1}$

we were able to define the most unfavorable range of frequency of external perturbations of the system studied (Fig. 2), and to make recommendations for design.

Determination of stability by electrical simulation methods is particularly useful when a high-order system of differential equations is involved and analytical investigation is laborious for linear systems and impossible for nonlinear. The system (2) above is a special case. An investigation of stability was carried out on MNB-1 machines for a more complete representation of the system, taking into account hydrodynamic and thermodynamic effects. In this case unsteady heat transfer in the reactor was described by a system of differential equations of the 18th order.

To assess the error involved in solving linear systems on an MNB-1, the problem of determining the isotopic composition of a fuel element of the No. 1 Atomic Power Station was solved, and the results compared with theory and published experimental data [4]. The system of equations for isotopic composition has the form:

$$\frac{dz_1}{ds} = b_{11}z_1; \quad \frac{dz_2}{ds} = b_{21}z_2 + b_{22};$$

$$\frac{dz_3}{ds} = b_{31}z_3 + b_{32}z_2, \quad \frac{dz_4}{ds} = b_{41}z_4 + b_{42}z_3. \qquad (3)$$

The constants of systems (1), (2), and (3) were taken from the data of [5]. The computer solution of (3) is given in Fig. 3. The data obtained for 12.5% burn-up differ by less than 1.5% from calculated values given in [4]. The solution of more complex linear systems involves greater errors, but these do not usually exceed a few percent.

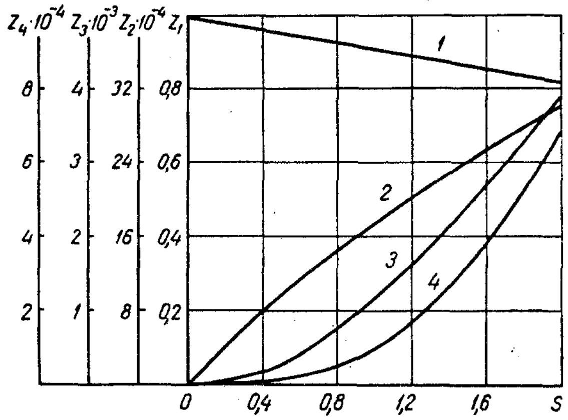

Fig. 3. Variation of isotopic composition of a fuel element as a function of reactor run-time: 1 – Z_1; 2 – Z_2; 3 – Z_3; 4 – Z_4

NOTATION

n – average neutron density in reactor; c_i – concentration of nuclei emitting delayed neutrons; λ_i – disintegration constant of i-th group; β_i – fraction of delayed neutrons of group i per neutron born; $\beta = \Sigma\beta_i$; l – mean lifetime of instantaneous neutrons; Δk – reactivity; $M_{\Delta k}$ – scale of reactivity; x – length of economizer section; y – mass of vapor in core; T_1 and T_2 – fuel element wall temperatures in economizer and evaporator sections; Δk_p – external reactivity; a_{ij} and b_{ij} – constant coefficients; $z_1 = \rho_5/\rho_{05}$, $z_2 = \rho_9/\rho_{05}$, $z_3 = \rho_{40}/\rho_{05}$, $z_4 = \rho_{41}/\rho_{05}$ – relative concentrations of U^{235}, Pu^{239}, Pu^{240}, Pu^{241}; s – reactor run-time; m – coefficient, constant for a given reactor.

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11 May 1964

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