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83

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SIMULATION OF THE ORSORT BUTTERMILK REACTOR, LOSS OF FUEL FLOW

This discussion is supplementary to that in CF 58-1-3, Analog Computing, January 17, 1958, and in CF 57-1-1, Reactor Controls, January 5, 1957.

A. Steady State Conditions

When this reactor is operating at its steady state design condition, the fuel temperature rises from 850°F to 1150°F during the 5 second time interval in the reactor. Thus, the 350 megawatts of nuclear power is raising the fuel temperature at an average rate of 60°F per second. The mean temperature of the fuel in the reactor is 1000°F.

In addition, a portion of the delayed neutrons are produced outside the reactor, thus k must exceed unity to hold the reactor at steady state. Refer to Equation (61), page 68 of CF 57-1-1. The values of α_i for this problem were computed by Equation (57), page 64 of CF 57-1-1. Although the symbols were defined in CF 57-1-1, it should be noted that α_i is the fraction of the delayed neutrons useful to the reactor with circulating fuel.

$$\alpha_i = 1 - \frac{1}{\lambda_i \tau_1} \left(\frac{e^{\lambda_i \tau_2} - 1}{e^{\lambda_i \tau_2} - e^{-\lambda_i \tau_1}} \right) (1 - e^{-\lambda_i \tau_1}) \quad (57)$$

τ_1 = time inside reactor = 5.0 sec

τ_2 = time outside reactor = 6.67 sec

The properties of the delayed neutron groups for this problem and the values of α_i are listed in Table I.

TABLE I

Delay Group	$\beta_i \times 10^5$	$\lambda_i (\text{sec}^{-1})$	α_i	$\beta_i \alpha_i \times 10^5$
1	25	14.0	0.986	24.6
2	84	1.61	0.876	73.6
3	240	0.453	0.622	149.2
4	210	0.154	0.453	95.3
5	170	0.0314	0.431	73.4
6	26	0.0125	0.429	11.2

$$\sum \beta_i \times 10^5 = 755$$

$$\sum \beta_i \alpha_i \times 10^5 = 427.3$$

From Equation (61), page 68 of CF 57-1-1,

$$K = 1 + \sum \beta_i (1 - \alpha_i) \quad (61)$$

$$\text{or, } K = 1 + \sum \beta_i - \sum \beta_i \alpha_i$$

Thus, the approximate value of K may be found.

$$K = 1 + 755 \times 10^{-5} - 427.3 \times 10^{-5}$$

$$K = 1 + 327.7 \times 10^{-5} = 1.003277$$

$$\text{or, } K = 1.00328$$

Therefore; δK to hold the reactor at steady state is 0.3277% when the fuel is circulating. This calculated value of δK is probably more accurate than the value given on page 32 of CF 58-1-3 because the values of α_i were arithmetically computed rather than being read from the curves on ORNL-IR-DWG 8919, page 66 of CF 57-1-1.

The temperature coefficient of reactivity of the fuel is $-2.89 \times 10^{-5}/^{\circ}\text{F}$, requiring a mean fuel temperature rise of 346°F to reduce k by 1%, as in CF 58-1-3.

B. Instantaneous Loss of Fuel Flow

Upon the instantaneous loss of the flow of the fuel, the initial rate of increase of the mean fuel temperature is 60°F per second because the nuclear power of 350 megawatts will produce this rate of temperature increase. The rise in temperature will act through the negative temperature coefficient of reactivity to reduce the power, but the temperature will continue to rise.

The power will asymptotically approach zero and the temperature will increase at a decreasing rate. The temperature will never decrease because there is no loss of heat from the reactor under the assumed conditions.

When the fuel flow ceases, the contributions of the delayed neutrons would reach their normal stationary fuel values if the reactor could be operated at steady state with no flow. The original value of k with circulating fuel was 1.00328. An increase in the mean fuel temperature of 113.5°F would cancel the excess k by virtue of the negative fuel temperature coefficient of $2.89 \times 10^{-5}/^{\circ}\text{F}$. However; there is no mechanism for heat removal, thus the only steady state value of power is zero with no flow.

C. Simulator Connections

The elementary road map for simulating the loss of fuel flow incorporates the nuclear reactor, the means for generating the mean fuel temperature, and the means for control of the nuclear reaction by the negative temperature coefficient and control rod. Amplifiers 39 and 40 were coupled to the networks which simulate the source, the prompt neutrons, and the delayed neutrons.

Elementary Road Map for Simulation of Loss Fuel of Flow in ORSORT
Buttermilk Reactor.

The source was zero. The delayed neutron network was initially set up to simulate the steady state condition for the circulating fuel with the reactor output power from amplifier 39 being 70 volts. At the start of the transient, this network was switched to produce the precursors of delayed neutrons at the same rate as for stationary fuel. There are two pots for each delayed neutron group. One pot sets the initial value of $P_0 \beta_i \alpha_i \times 10^3$, P_0 being the initial power level in volts, α_i and β_i being previously defined. The second pot for each group of delayed neutrons sets the value of $\beta_i \alpha_i \times 10^5$ for the new condition of operation. The initial power level, P_0 , was 70 volts. The pot settings are listed in Table II. The values of $\beta_i \alpha_i \times 10^5$ are taken from Table I.

TABLE II

Delay Group	Initial Condition Settings $P_0 \beta_i \alpha_i \times 10^3$	Operating Settings $\beta_i \alpha_i \times 10^5$
1	17.2	25
2	51.6	84
3	104.5	240
4	66.7	210
5	51.4	170
6	7.8	26

It should be noted that the value of α_i in the operating settings was unity; thus, the operating settings are actually $\beta_i \times 10^5$

Amplifiers 39 and 40 were connected and the control rod, pot 73, was adjusted to obtain +70 volts at the output of amplifier 39 under the initial conditions.

Amplifier 30 provided an output one-fifth of that of amplifier 39.

Amplifier 38 was connected as an integrator to compute the rise in fuel temperature, with an initial value of zero volts. Pot 60 was set to provide a voltage ratio of 0.429 in order that the output of amplifier 38 would rise 6 volts per second when the output of amplifier 39 was +70 volts. Thus, the fuel mean temperature rise would be 60°F per second at a nuclear power of 350 megawatts.

Amplifier 33, pots 13 and 73, servo multiplier 3, and amplifier 31 provided the circuit for introducing the control rod and negative temperature coefficient. An output of +100 volts from amplifier 33 would produce an excess k of +2%. A voltage rise of 34.6 volts from amplifier 38 would introduce an excess k of -1%. This is equivalent to a temperature rise of 346°F . Refer to CF 58-1-3.

At the initial condition, it was found that the potential from pot 73 was 16.6 volts with 70 volts out of amplifier 39. The equivalent excess k due to this rod setting was 0.332%.

The circuit is similar to a portion of that of the complete system in ORNL-LR-DWG 26401, CF 58-1-3.

D. Operation

The transient was started by switching the delayed neutron circuits from their initial condition settings to their operating settings. Amplifier 38 was switched into the circuit as an integrator to indicate the rise in fuel mean temperature.

E. Comparison of Circulating Fuel and Stationary Fuel

A second transient was obtained under the assumption that the fuel was stationary, but had the heat capacity and temperature coefficient of the case with circulating fuel. The heat would be removed by some sort of circulating coolant which would not affect the delayed neutrons.

Loss of Fuel Flow; Simulation of ORSORT Buttermilk Reactor.

A sudden loss of heat removal was examined. The power was found to decrease somewhat more slowly than for the case of an abrupt loss of fuel flow in the circulating fuel reactor. The temperature rise was somewhat faster with stationary fuel. The sudden loss of fuel flow in the circulating fuel case tends to place the reactor on a positive period because of the additional delayed neutrons which had previously been produced external to the reactor. However; the initial levels of the precursors of the delayed neutrons are low compared to the stationary fuel case, and apparently this reactor could be placed on a short negative period by less reduction in k than for the stationary fuel case.

A reactor system having a different fuel heat capacity, temperature coefficient, or fuel circulation rate may not exhibit this particular relation between the stationary fuel and circulating fuel cases. No general conclusions should be drawn from this one example; each system must be individually examined.

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