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A LABORATORY
REACTOR SIMULATOR
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1.0 INTRODUCTION

A laboratory reactor simulator has been designed and built to be used with the reactor controller breadboards. This simulator is used to perform closed loop tests on the reactor controller breadboard preliminary to testing the breadboard with the reactor simulation on an analog computer. By using the laboratory reactor simulator, trouble shooting, preliminary adjustments, and limited tests can be made on the reactor controller without requiring expensive computer time.

2.0 GENERAL DESCRIPTION

The laboratory reactor simulator provides means to close the log N loop in the subpower range and both the log N and temperature loops in the power range as well as providing a simulated pressure signal.

The laboratory reactor simulator has the capability of operating with reactor controller breadboards operating on base computing voltages of either 10 volts or 100 volts. The reactor simulator itself operates on a 100 volt computing level but will operate with reactor controller breadboards operating on either of the computing voltages by changing the gains of the input and output amplifiers by means of switches on the simulator.

The simulator is constructed in a chassis which can be mounted in a standard relay rack. The reactor simulator is shown in Figures 1 to 5, and the block diagram and wiring schematic are shown in Figures 6 and 7.

Also included for use with the laboratory reactor simulator is its own power supply located in a separate chassis.

3.0 OPERATIONAL DESCRIPTION

The interconnections of the laboratory reactor simulator and the reactor controller are shown in Figure 8. The reactor controller and simulator operate together in the following manner. The reactor controller receives a startup signal, SUS, simulated by closing a switch on the breadboard. From the startup signal, the controller supplies a demanded control drum actuator angular position, θ_D , to the simulator. The reactor simulator then calculates the logarithm of the neutron density, $\log N$ and gives an output which is the logarithm of the measured neutron density, $\log NM$. This signal is fed back to the reactor controller which regulates the angular position of the control drum actuator until the measured neutron density becomes approximately 1% of full power level. Once the 1% level is reached the reactor controller maintains this level until the power range control system is activated.

The power range is activated by the laboratory reactor simulator supplying a pressure ramp signal to the reactor controller and other portions of the reactor simulator. This pressure ramp simulates the pressure supplied by the propellant pump. The pressure ramp is started when a switch on the front panel of the simulator is thrown to the ramp increase position. The reactor controller breadboard then calculates a demanded thrust chamber temperature from the pressure signal and supplies a demanded control drum actuator angular position to the laboratory reactor simulator. The simulator again calculates the logarithm of the neutron density and feeds the logarithm of measured neutron density back to the reactor controller. From the neutron density and the thrust chamber pressure, the reactor simulator calculates the thrust chamber temperature which is also fed back to the reactor controller. The reactor controller then regulates the

position of the control drum actuator until the thrust chamber temperature and pressure reach full power levels. The simulator is brought back to the 1% power level by switching the pressure ramp switch on the reactor simulator to the ramp decrease position. The simulated pressure out of the reactor simulator is then decreased according to a decreasing ramp function.

4.0 SYSTEM DESCRIPTION

The laboratory reactor simulator has three functions:

1. Calculates the logarithm of the neutron density, $\log N$ from the demanded control drum actuator position, θ_D .
2. Provides a pressure signal to simulate the mixing chamber pressure, P_C .
3. Calculates the mixing chamber temperature, T_C , from $\log N$ and P_C .

A block diagram of the laboratory reactor simulator which accomplishes these three functions is shown in Figure 6.

The demanded control drum angular position, θ_D , received from the laboratory reactor controller first passes through an inverter stage. The purpose of the inverter is to provide a positive θ_D signal and provide the ability to accept the θ_D signal from either 10 volt or 100 volt systems. The output of the inverter then passes into the actuator simulator. The transfer function of the control drum actuator system is the second order approximation

$$H(S) = \frac{1}{\left(\frac{S}{W_0}\right)^2 + 2\zeta\left(\frac{S}{W_0}\right) + 1}$$

where W_0 = natural frequency = 10π radians/second

ζ = damping factor = 0.5.

The output of the actuator simulator is the actual control drum position, θ . From the control drum position, θ , the logarithm of neutron density, $\log N$, is calculated from the drum worth and reactor characteristics. The drum worth is based on the reactivity, δk , being related to θ by a $\sin^2 \theta$ curve.

After criticality is established, the stable period is related to the reactivity by the Inhour formula. This relationship is combined with the relationship between control drum position and reactivity to form a function of stable inverse period, γ , versus control drum position, θ . When the drums are moving, a transient period exists and is approximated in the laboratory reactor simulator. The stable inverse period and transient inverse period are combined and then integrated to calculate the logarithm of neutron density.

The $\log N$ signal is then passed through a nuclear instrumentation lag circuit. The lag circuitry is designed to give a fixed lag of 0.1 seconds. This lag represents the longest lag anticipated in any range of the nuclear instrumentation. Provisions are also provided to switch off this lag. When operating in the power range, this lag is removed, since the lag of the actual instrumentation in this range is expected to be less than 0.01 seconds and hence is small enough to be neglected. The output is, therefore, the $\log NM$ which is fed back to the reactor controller.

The reactor power is proportional to the thrust chamber pressure, P_c , and the square root of the thrust chamber temperature, T_c . Since the power is assumed

to be proportional to the neutron flux density, this parameter is known. The thrust chamber pressure is known from the pressure simulator of the laboratory reactor simulator. From P_c and $\log N$, the thrust chamber temperature can be calculated. Since the neutron flux density is in log form, it is convenient to calculate T_c in log form; using logarithms also avoids the use of a multiplier. The $\log N$ signal is passed through a lag circuit to simulate the thermal lag in heating the reactor core. This signal is subtracted from $\log P_c$ signal to obtain $\log T_c$. The $\log P_c$ signal was obtained from the P_c signal by a log amplifier. The $\log T_c$ signal is passed through an anti-log amplifier to obtain the thrust chamber temperature, T_c .

The pressure simulator is programmed to provide a pressure ramp to simulate the thrust chamber pressure, P_c . This pressure ramp is identical to that used to run reactor controller tests with analog computer simulation as reported in WANL-TME-270 "NERVA Engine Reactor Control System: Preliminary Synthesis and Analysis", February 8, 1963.

5.0 LIMITATIONS

The laboratory reactor simulator was designed using basic assumptions and simplifications. These assumptions and simplifications were necessary to design and build the simulator in a single chassis. These assumptions and simplifications impose certain limitations on the reactor simulator, but if these limitations are properly understood, they do not restrict the usefulness of the simulator.

Several factors which effect the reactivity, δk , were neglected in the design of the simulator. The reactivity was assumed constant with temperature and

hydrogen density. In reality, the reactivity will decrease with increasing temperature and will increase with increasing hydrogen density. The length of time the reactor will be operating will be too short for factors such as fuel depletion or fission product poisoning to affect the reactivity, and therefore, they were neglected.

The reactor characteristics are simulated by using the stable and transient inverse periods and not by solving the actual kinetic equations. Although the reactor characteristics are approximate, a comparison of the operation of the reactor controller breadboard on the laboratory reactor simulator and on the analog computer simulation show that the reactor characteristics in the laboratory reactor simulator are sufficient for the intended purpose of the simulator.

The nuclear instrumentation was assumed to have a constant time lag in the subpower range and zero time lag in the power range. The actual instrumentation will have a time lag which varies with the neutron density. The time lag used in the simulator is the most severe expected in the actual instrumentation range. In the power range, the time lag of the actual instrumentation is expected to be small enough that it can be neglected. The time lag of the thermocouple is also assumed to be constant. The time lag of the thermocouples used in the reactor will vary with the flow rate. Again, the time lag used in the simulator was taken to be the largest expected time lag of the thermocouples.

The thrust chamber pressure signal assumes the pump will bootstrap and the pressure will increase according to a fast ramp and then a slower ramp. The ramp increase

in pressure was based on the latest available information on the pump at the time the simulator was designed.

6.0 CONCLUSIONS

A laboratory reactor simulator has been designed and built so that reactor controller breadboards and eventually prototype controllers can be operated closed loop without the use of an analog computer. The design of the laboratory reactor simulator was based on the reactor equations. While some assumptions were used to simplify the reactor equations, they do not limit the usefulness of the reactor simulator, but in no way is it intended to replace or eliminate the need for testing breadboard reactor controllers on a good analog model of the reactor and engine.

LABORATORY REACTOR SIMULATOR - FRONT VIEW

FIGURE 1

LABORATORY REACTOR SIMULATOR. - RIGHT REAR VIEW
FIGURE 2

LABORATORY REACTOR SIMULATOR - LEFT REAR VIEW
FIGURE 3

LABORATORY REACTOR SIMULATOR - BOTTOM VIEW
FIGURE 4

LABORATORY REACTOR SIMULATOR AND REACTOR
CONTROLLER BREADBOARD III IN OPERATION

FIGURE 5

SCHEMATIC DIAGRAM OF LABORATORY REACTOR SIMULATOR

FIGURE 7