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NP000

Order
pass

WANL-TME-1270

October, 1965

Westinghouse Astronuclear Laboratory

Analysis of PCV-41 Control System (U)

File

Lesson 21

330 psi

1600°R T = 21

MASTER

60 - 3000°R hold

1.4 x 330 2 sec

2000°R = 1.4 x

normal port cold flow

330

495 x 1.4

2 sec 495

50 psi = set max
not 26

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Astronuclear
Laboratory

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REFERENCE

- (1) E. Rappaport, "KIWI B-1B Control Systems Test Cell A", LAMS-2966
November 19, 1963 (UNCL.)

SUMMARY

A redesign of the emergency cooldown system was necessary before NRX/EST testing. The system operates by automatically regulating the position of PCV-41 valve to control the gas flow to the test article. The requirements on the PCV-41 system were to maintain the tie rod temperature below 1600°R, and a 22 pounds per second gas flow rate at the nozzle tubes when operating in the EST configuration. *not used by test rig.*

Analytical and analog computer studies of the PCV-41 System were conducted to determine the controller compensation necessary for stable operation of the control system. Based on these studies the following controller was recommended:

$$\frac{\alpha_d}{P_e} = \frac{.1 (1 + S)}{S (1 + .01S)} \frac{\text{volts}}{\text{Psi}}$$

$$\alpha_d = \text{PCV-41 valve angle demand.}$$

$$P_e = \text{Difference between demanded pressure and nozzle torus pressure (feedback pressure).}$$

BACKGROUND

The emergency cooldown system used for protection of the test article in the event of an emergency shutdown is the automatic control of PCV-41 valve position. A desired pressure downstream of PCV-41 is maintained by a closed loop control system which regulates the position of PCV-41. The system is designed to expel, at an acceptable rate, the liquid in the system at the time of shutdown and to provide sufficient gas flow to safely cool the reactor and nozzle.

Figure 1 is a piping diagram of the PCV-41 system for NRX/EST testing. This system is the same as NRX-A3 except for the addition of the FE-X venturi. This venturi is necessary to determine flow to the test article when operating in the EST configuration.

The PCV-41 system used for NRX-A3 was designed to maintain P-41 at 60 percent of the nozzle torus pressure at the time of shutdown. If the gas flow through FE-10 is sonic, the nozzle torus pressure is lower than P-41. The pressure difference between P-41 and the nozzle torus pressure is dependent on the gas flowrate through FE-10. If the gas flowrate through FE-10 is sub-sonic, the nozzle torus pressure is nearly the same as P-41. For sonic gas flow through FE-10, the pressure drop from P-41 to the nozzle torus can be as much as 50 percent of P-41. Since the actual function of the system is to control the gas flowrate into the nozzle tubes by controlling the nozzle torus pressure, it is desirable to use the nozzle torus pressure as the controlled variable and feedback signal. To ensure the proper operation of the emergency cooling system, it was decided to redesign the PCV-41 system for the NRX/EST tests.

For the NRX/EST tests, the PCV-41 system must provide sufficient gas flow for two possible shutdown conditions. In the NRX mode of operation, the system is the same as that used for NRX-A3. That is the volume of liquid and gas in the system at the time of shutdown is the same as in previous NRX tests. With the system in the EST configuration at the time of shutdown, the volume of liquid in the system is considerably less than in the NRX configuration. The two possible initial conditions require that the PCV-41 system be capable of providing sufficient cooling for the test article in both modes of operation, but it must not overcool the system.

INTRODUCTION

The function of the PCV-41 control system is to provide sufficient hydrogen gas flow to cool the reactor and nozzle in the event of an emergency shutdown. This operation is accomplished by a closed-loop pressure control system which maintains the nozzle torus pressure at a value determined as satisfactory for the initial conditions of shutdown. Demanded nozzle torus pressure for the analysis of the PCV-41 controller was 600 psi based upon the recommendation of Reactor Analysis. The demanded nozzle torus pressure is based on maintaining the tie rod temperature below 1600°R . Since the function of the PCV-41 system is to maintain the nozzle and core temperatures at acceptable levels in the event of an emergency shutdown, the pressure demand signal for the PCV-41 control system during reactor testing will be derived from the station 26 average temperature. Station 26 temperature was chosen because it is an in-core temperature and will give the best indication of the state of the test article in the event of an emergency shutdown. The pressure demand will be determined by a function generator which establishes the nozzle torus pressure desired, in the event of an emergency shutdown, for the present reactor temperature. Once an emergency shutdown occurs, the demanded nozzle torus pressure remains constant at the value determined at the time of shutdown. Since this analysis was concerned only with the operation of the PCV-41 control system after an emergency shutdown, it was not necessary to simulate the station 26 temperature tracking for this analysis.

Subsequent to the initial design of the PCV-41 control system, an additional system requirement on gas flowrate into the nozzle was established. For 100 percent power as an initial condition of shutdown, it is required that the PCV-41 system maintain a minimum gas flowrate of 22 pounds per second into the nozzle torus. [This flowrate is required to protect the nozzle tubes when the system is operating in the EST configuration.] The additional flow rate requirement made it necessary to increase the steady state demanded nozzle torus pressure to 660 psi. In addition to the increase in steady state demanded nozzle torus pressure, it was necessary to add an exponentially decaying demand signal to the steady state signal. This was necessary to insure that the gas flow to the nozzle torus would not go below 22 pounds

per second during the transient period. It should be pointed out that there are two transient periods when the PCV-41 system is activated. The first transient occurs at the instant of shutdown. The second occurs when all of the liquid in the system at the time of shutdown has been forced through the nozzle tubes.

ANALYSIS OF PCV-41 CONTROL SYSTEM

A stability study of the PCV-41 pressure control loop for gas flow was performed using the following assumptions:

1. Sonic flow through all venturies, nozzle tubes, and PVC-41.
2. Pressure scaling of 100 psi per volt.
3. Valve position scaling of 1% open per volt.
4. An isothermal pipeline model to estimate the flow transfer function delays of the pipelines (Reference 1).
5. Valve dynamics:

$$\frac{\text{Measured Valve Position}}{\text{Demanded Valve Position}} = \frac{1}{\left(\frac{S}{94}\right)^2 + \frac{2(.6)}{94} S + 1}$$

Figure 2 is a block diagram of the system analyzed.

Two pressure controllers were analyzed:

1.
$$\frac{\alpha_d}{P_e} = \frac{10}{S} \frac{\text{volts}}{\text{volt}}$$
2.
$$\frac{\alpha_d}{P_e} = \frac{10}{S} \frac{(1 + 1.01 S)}{(1 + .01 S)} \frac{\text{volts}}{\text{volt}}$$

where α_d is the PCV-41 valve angle demand and P_e is the error between the demanded nozzle torus pressure and the measured nozzle torus pressure.

The relative stability of the PCV-41 Control System using the above controls is indicated in Figures 3 and 4. Figure 3 is the response of the system with the integral controller. The gain margin of the system is 18 db and the phase margin is 57 degrees. The system bandwidth is 4 radians per second. Figure 4 is the response of the system using the second controller. The gain and phase margin of the system using the second controller are 13 db and 75 degrees. The system bandwidth is 17 radians per second. Results of the analysis show that the system using the proportional plus integral controller will best meet the established requirements.

ANALOG COMPUTER RESULTS

An analog computer simulation of the PCV-41 Control System was used to study the operation of the controllers. The analog model simulated the gas and liquid volumes in both the NRX and EST configurations. This made it possible to evaluate the system performance for both liquid and gas flow through the nozzle tubes as well as the transition from liquid to gas flow.

Because reactor and feed system models were not available at the time of the PCV-41 system study, it was necessary to perform this study with a constant flow impedance beyond the nozzle tubes. Since the reactor heat exchanger was not simulated, the tie rod temperature was not available to record. Therefore, the tie rod temperature had to be determined by the TNT digital code. Flow shutdowns using the PCV-41 Control System in the NRX and EST modes were investigated. Frequency responses of the system using the 10/S controller were taken to evaluate the assumptions made for the analytical study.

Table I is a summary of the results of the analog computer runs using a 600 psi demand signal. These computer runs were made before the nozzle requirement of 22 pounds per second was specified. The analog runs were made with the pipeline downstream of PCV-41 valve 100 percent pressurized at the time of shutdown. Figures 5 and 6 are the analog runs of the PCV-41 System using the proportional plus integral controller of the analytical study. The system was investigated in both the NRX and EST modes of operation.

Average tie rod temperature for the system using the proportional plus integral controller and a demanded pressure of 600 psi was determined by the TNT digital code. Input data for the code were nozzle flow and nozzle pressure as a function of time. Results of its calculations were a maximum average tie rod temperature of 1436°R in the NRX mode and 1525°R in the EST mode which meets the system requirement of maintaining the average tie rod temperature below 1600°R.

Results from analog computer frequency response measurements are plotted in Figure 7. This figure is comparable to the Nichols Chart of Figure 3. The analog data indicates a gain and phase margin of 23 db and 47° . The predicted values of gain and phase margin are 18 db and 57° . The system bandwidth is 5 radians per second for the analog study as compared to 4 radians per second in the analytical study. The results indicate that the analog model has a somewhat higher gain and less phase shift than the system assumed for the analytical study.

The analog computer frequency response data were used to obtain the operating characteristics of the PCV-41 System with the proportional plus integral controller. This was done by incorporating the controller lead lag network into the frequency response data. The results of this procedure are plotted in Figure 8. The gain and phase margin of the system, based on analog computer frequency response data, are 16.5 db and 77° . The values for gain and phase margin from the analytical study were 13 db and 75° . The system bandwidth from Figure 8 is 27 radians per second. The bandwidth from the analytical study was about 16 radians per second. The discrepancies between the analog results and the analysis study are again due to the higher gain and less phase shift of the analog model as compared to the assumed system for the analysis study.

Results of this study show that the analog model of the system is very similar to the system assumed for the analytical study. It should be pointed out that simplifying assumptions were made in both cases, and that the close agreement of the two results is very satisfactory.

ANALOG COMPUTER STUDY TO OBTAIN DESIRED FLOW RATE

In order to satisfy the nozzle tube requirement of 22 pounds per second gas flow for 100 per cent power initial conditions, the steady state pressure demand was increased to 660 psi and an exponentially decaying signal of 235 psi was added to the steady state demand signal. The time constant of the exponentially decaying signal was 0.5 seconds. The analog traces of the NRX and EST modes are shown in Figures 9 and 10. These traces show that the nozzle torus gas flow never goes below 22 pounds per second. A comparison of Figures 6 and 10 show the addition of the exponentially decaying pressure demand to the steady state pressure

demand eliminates the flow undershoot for the EST configuration.

The system requirement of 22 pounds per second minimum gas flow rate at the nozzle tubes was established by AGC for the EST mode of operation. No requirement has been established for the NRX configuration. It has not been determined if the exponentially decaying demand signal is necessary for the NRX mode of operation. The analog computer results are summarized in Table II.

CONCLUSIONS

Based on the analog computer and analytical studies performed, the proportional plus integral controller is recommended for the PCV-41 system. As a result of this study, Control Systems Engineering recommended the following controller compensation:

$$\frac{\Delta d}{P_e} = \frac{10 (1 + S)}{S (1 + .01S)} \frac{\text{volts}}{\text{volt}},$$

This controller is based on a scaling of 100 psi per volt for pressure and one per cent open per volt for PCV-41.

In order to verify the analog and analytical models used for the design of the PCV-41 system, frequency response data as well as shutdown data should be obtained during the facility checkout.

TABLE 1
 SUMMARY OF
 PCV-41 CONTROL SYSTEM - ANALOG SIMULATION RESULTS
 100% POWER CONDITIONS
 DEMANDED NOZZLE TORUS PRESSURE = 600 PSI

	NRX System	EST System
Compensation	B**	B**
Minimum Nozzle Torus Flow	18 lb/sec	14 lb/sec
Minimum Nozzle Torus Pressure	330 PSI	360 PSI
Steady State Nozzle Torus Flow	18 lb/sec	20 lb/sec
Steady State Nozzle Torus Pressure	600 PSI	580 PSI
Time From Shutdown to Steady State	5 sec	4.5 sec
Time For Liquid to be Expelled	1.75 sec	.2 sec
Time Nozzle Torus Flow is Below 20 lb/sec	0 sec	4.2 sec
Maximum Average Tie Rod Temperature	1436°R	1525°R

**B $\frac{\alpha d}{P_e} = \frac{10 (1 + 1.01S)}{5 (1 + .01S)} \frac{\text{volts}}{\text{volt}}$ Assumed Scaling: 100 $\frac{\text{PSI}}{\text{volt}}$; $\frac{1\%}{\text{volt}}$

TABLE II
SUMMARY OF
PCV-41 CONTROL SYSTEM - ANALOG SIMULATION RESULTS
100% POWER CONDITIONS
DEMANDED NOZZLE TORUS PRESSURE = 660 PSI

	NRX System	EST System
Compensation	B**	B**
Minimum Nozzle Torus Flow	22 lb/sec	22 lb/sec
Minimum Nozzle Torus Pressure	500 PSI	540 PSI
Steady State Nozzle Torus Flow	22 lb/sec	22 lb/sec
Steady State Nozzle Torus Pressure	660 PSI	660 PSI
Time From Shutdown to Steady State	3.125 sec	2.08 sec
Time For Liquid to be Expelled	1 sec	.1 sec
Time Nozzle Torus Flow is Below 22 lb/sec	0 sec	0 sec
Maximum Average Tie Rod Temperature		

**B $\frac{d}{P_e} = \frac{10 (1 + 1.01S)}{S (1 + .01S)} \frac{\text{volts}}{\text{volt}}$ Assumed Scaling: 100 $\frac{\text{PSI}}{\text{volt}}$; $\frac{1\%}{\text{volt}}$

Flow Venturi
FE-10
FE-X
FE-7

Position Control Valve
PCV-41

Analog Control Valve
ACV-3

Check Valves
DCV-1
DCKV-3
CV-645
CV-872

Liquid Line Filter
F-39

P-124 = Nozzle Torus Pressure

PIPING DIAGRAM OF PCV-41 SYSTEM FOR NRX/EST TEST

FIGURE 1

$P_{NT} \rightarrow$ Nozzle Torus Pressure

(1) Pipe Line Delay $\rightarrow$ PCV-41 to FE 10

(2) Pipe Line Delay $\rightarrow$ FE 10 to FEX

(3) Pipe Line Delay $\rightarrow$ FEX to Nozzle Torus

*Due to choking of the nozzle tubes the nozzle torus pressure can be calculated.

BLOCK DIAGRAM OF PCV-41 CONTROL SYSTEM

FIGURE 2

DYNAMIC RESPONSE OF PCV-41 SYSTEM
BASED ON ANALYSIS DATA

$$\text{COMPENSATION} = \frac{10}{S} \frac{\text{VOLTS}}{\text{VOLT}}$$

FREQUENCY IN RAD/SEC.

FIGURE 3

DYNAMIC RESPONSE OF PCV-41 SYSTEM
BASED ON ANALYSIS DATA

$$\text{COMPENSATION} = \frac{10(1+1.01s)}{s(1+.01s)} \quad \frac{\text{VOLTS}}{\text{VOLT}}$$

FREQUENCY IN RAD/SEC.

FIGURE 4

DYNAMIC RESPONSE OF PCV-41 SYSTEM BASED
ON ANALOG COMPUTER DATA

COMPENSATION $\frac{10}{S}$ $\frac{\text{VOLTS}}{\text{VOLT}}$

FREQUENCY IN RAD/SEC.

FIGURE 7