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Numerical Analysis on Letdown System Performance Test for YGN 3

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Abstract

Integrated performance test of Chemical and Volume Control System (CVCS) was successfully performed in 1994. However, an extensive effort to correct hardware and software problems in the letdown line was required mainly due to the lack of adequate simulation code to predict the test accurately. Although the LTC computer code was used during the YGN 3&4 NSSS design process, the code can not satisfactorily predict the test due to its insufficient letdown line modeling. This study developed a numerical model to simulate the letdown test by modifying the current LTC code, and then verified the model by comparing with the test data. The comparison shows that the modified LTC computer code can predict the transient behavior of letdown system tests very well. Especially, the model was verified to be able to predict the "Stiction" phenomena which caused instantaneous fluctuations in the letdown backpressure and flowrate. Therefore, it is concluded that the modified LTC computer code with the ability of calculating the "Stiction" phenomena will be very useful for future plant design and test predictions.

1.0 Introduction

Integrated performance test for the Yonggwang Unclear Power Plant Unit 3 (YGN 3) CVCS was successfully performed on August 7, 1994. The purpose of the test was to ensure the performance of CVCS and Pressurizer Level Control System (PLCS). The test was performed by checking the CVCS and PLCS responses to an external disturbance during normal automatic operation mode. The test consists of (1) +5% step change, (2) -5% step change, (3) +10% step change, (4) -10% step change, (5) -1%/min ramp change up to 20% in the pressurizer level setpoint, and (6) the Letdown Control Valve transfer test. However, there were large losses of man-power and time until resolving test problems (e.g., unwanted Letdown Relief Valve opening) and obtaining optimized CVCS/PLCS control setpoints, since there was no computer code to predict the test results. The test, therefore, concluded that a simulation computer code need to be developed to predict the transient behavior of the letdown system test.

This study intends to develop a computer code which is able to simulate the integrated letdown test and to verify/validate the code by comparing the simulation results with the test data of YGN 3[1]. The computer code was initially based on LTC computer code[2], [3], one of NSSS performance computer codes for YGN 3&4, by modifying the letdown system. Although the previous study[4] attempted to simulate the test results, the new computer code has been upgraded by (1) considering Component Cooling Water System and its control logic, (2) adding the test results of another Letdown Control Valve (P valve), and (3) reflecting the stiction phenomena of the Letdown Control Valve and Backpressure Control Valve.

2.0 Description of Letdown System and its related controllers

2.1 Description of Letdown System

As shown in Figure 1, the hot reactor coolant, exited from Cold Leg, is cooled down by the cold charging flow in the Regenerative Heat Exchanger (RHX) and then depressurized to approximately 460 psig by the Letdown Control Valve (LCV). The LCV consists of two redundant parallel valves (i.e., Q and P valves). After passing the LCV, the letdown flow passes through the Letdown Heat Exchanger (LHX) in which the letdown flow is further cooled to 120 °F by the cold Component Cooling Water (CCW) and is maintained to 460 psig by the Backpressure Control Valve (BPCV). Finally, the letdown flow is further depressurized by the BPCV before it reaches the Volume Control Tank (VCT).

2.2 Description of the LCV, BPCV, and CCW Control Valve Controllers

Above-mentioned LCV is opened or closed by the position demand signal of PLCS. As shown in Figure 1, the PLCS generates the pressurizer (PZR) level deviation error signal, i.e., measured level minus programmed level setpoint. After passing Proportional-Integral (PI) Controller, the error signal is filtered by a LAG unit. The filtered signal is limited by Signal Limiter whose function is to cut off the signal within desired control ranges and limit the maximum/minimum opening of the LCV. Through this process, the LCV position is determined and the letdown flow rate is controlled to maintain RCS water inventory. In order to maintain letdown flow at a desired temperature, the CCW flow to the LHX is controlled by the position demand signal of CCW control valve according to the fluid temperature at the LHX discharge. The signal is generated from PI controller whose function is to calculate the temperature error (i.e., measured letdown temperature minus temperature setpoint (T_{set})) and compensate it. In the meantime, the measured backpressure between the LHX discharge and the BPCV suction is compared to the backpressure setpoint (P_{set}) and, then, is compensated by PI controller. The compensated signal determines the opening position of BPCV and controls the backpressure at the desired setpoint.

3.0 Methodology

The current LTC code does not model the major letdown components and controllers (i.e., LHX, BPCV, BPCV Controller, CCWS, CCW Controller, and Letdown Relief Valve) nor letdown piping volume. Therefore, in order to simulate the letdown performance test, this study revised the current letdown model as discussed in the following subtsections.

3.1 Revised Letdown Model

As shown in Figure 1, the revised letdown model consists of two control volumes: Control Volume I bounds from the discharge of LCV to the suction of LHX and Control Volume II does from the suction of LHX to the suction of BPCV.

3.1.1 Assumptions

In order to revise the current letdown model and predict the transients of integrated letdown performance test, the following assumptions are introduced:

(1) The fluid within Control Volume I and II are homogeneous.
(2) The discharge pressure of BPCS is equal to the pressure of VCT (i.e., 64 psig) and is constant during transients.
(3) The response time from backpressure measurement to BPCV operation is 1.0 second, while the response time at the LCV is negligible.
(4) All heat losses except two heat exchangers is neglected.
(5) Stiction factors at LCV and BPCV are 0.02 and 0.0075, respecively, and are constant during valve moving based on YGN 3&4 test results. Stiction is a word coined by the valve industry to differentiate between sliding and static friction which is the force required to get the valve to move after it has been static.

3.1.2 Governing Equations

The mass conservation, energy conservation, and Bernoulli equations are separately applied at each of Control Volume I and II as follows:

$$\frac{dM_I}{dt} + \frac{dM_{II}}{dt} = m_1 - m_2 - m_3 \quad \text{------------------} \quad (1)$$

$$\frac{dU_I}{dt} + \frac{dU_{II}}{dt} = m_1 * h_1 - m_2 * h_I - m_3 * h_{II} - Q_{LDHX} \quad \text{------------} \quad (2)$$

$$\frac{P_I}{\rho} + \frac{V_I^2}{2*C} = \frac{P_{II}}{\rho} + \frac{V_{II}^2}{2*C} - \frac{\triangle P}{\rho} \quad \text{---------------} \quad (3)$$

where, m is flow rate, h is specific entalphy, Q_{LDHX} is energy dissipated from LHX, M is total fluid mass at control volume, P is pressure, V is velocity, $\triangle P$ is pressure drop due to friction loss, and C is unit conversion factor. Subscripts 1,2,3 mean the conditions at LCV, Relief Valve, and BPCV, respectively, while subscripts I and II represents Control Volume I and II, respectively.

In the meanwhile, total mass M, density ρ, internal energy U at each Control Volume are related as follows:

$M = \rho * V$ ------ (4) $\qquad \rho = f(P, h)$ ------ (5) $\qquad U = H - P*V*C_1$ ------ (6)

where, P is pressure, V is volume, H is enthalpy, and C_1 is conversion factor (144/778).

Flow rate at each valve is calculated from the following valve equation[5]:

$$m = \rho * Cv * (\Delta P \ / \ G)^{0.5} \quad (i = 1,2,3) \text{ -- } (7)$$

where, Cv is the flow coefficient, ΔP is pressure difference between suction and discharge sections, and G is specific density constant at each valve.

3.1.3 Boundary Conditions

The pressure and temperature at the inlet of Control Volume (CV) I are those of reactor coolant at the LCV discharge, while the pressure at the outlet of Control Volume II is 64 psig as described in Assumption (2). Also, the CCW temperature is 120 °F.

3.1.4 Programming

Based on Sections 3.1.2 and 3.1.3, the letdown model is programmed as shown in Figure 2. This flow chart shows that the inlet pressure of CV I is decided according to letdown flow (m_1), and this flow rate can be solved only by iteration method with Equation (6). That is, first, the pressure at CV I (P_1) is assumed, and then the pressure of CV II is calculated from the assumed pressure P_1 minus pressure drop due to Bernoulli equation. Next, based on these assumed pressures, Equations (1) through (6) are applied and iterated by the Half-Interval Search Method[6] until Equation (1) is satisfied. After obtaining the solution at one time step, this process is repeated with time interval of 0.1 second until final simulation time is reached.

3.2 Input Data

The major NSSS data used for YGN 3 letdown test and in this analysis are as follows:

Reactor power -------------------------------------- 0 %
Nominal letdown flow -------------------------------- 72.4 gpm (296.7 liter/min)
Nominal charging flow temperature ------------------- 120 °F (48.8 ℃)
Pressurizer volume ---------------------------------- 1800 ft^3 (50.98 m^3)
PZR water level setpoint at hot zero power ---------- 33 % of PZR level span
Pressurizer pressure -------------------------------- 2250 psia (158.2 kg/cm^2A)
Nominal cold leg temperature at hot zero power ------ 564 °F (295.5 ℃)
Nominal component cooling water temperature --------- 120 °F (48.8 ℃)
Volume Control Tank inside pressure ----------------- 64 psig (4.5 kg/cm^2G)

The as-built control setpoints for the PLCS, BPCV control system, and CCW system used during Integrated Letdown Test are shown in Table 1.

4.0 Results and Discussion

In this study, among six tests described in Section 1.0, three cases of (1) +10% step increase, (2) -10% step decrease, and (3) -20% ramp decrease with -1%/sec rate in pressurizer level setpoint are selected to be analyzed since these cases are representive sub-tests.

(1) +10% step increase in pressurizer level setpoint

Figures 3, 4, and 5 show the comparison of the test and simulation results for the PZR level, letdown flow rate, and backpressure, respectively, when the PZR level setpoint is rapidly increased from 33% to 43%. Due to the increased setpoint, PLCS initially generates the LCV closing signal in order to maintain the PZR level at the new increased PZR level setpoint (Fig.3), and the letdown flow reaches its minimum value at approximately 600 seconds after the test initiation (Fig.4). With letdown flow decreasing, the PZR level increases gradually, reaching to the new level setpoint, and then stabilized after approximately 3% overshoot (Fig.3). Even though the initial PZR level for the test was 31.5%, Figure 3 shows that the modified LTC code predictions follow the PZR level trend of Q valve test, while the result of P valve test is significantly different from that of Q valve test. As shown in Figure 4, the simulation is well predicting the stiction phenomena and, especially, the valve opening from the minimum LCV position at about 1200 seconds. Also, Figure 4 shows that the letdown flow trend of the simulation reasonably agree with that of Q valve test result. However, there are large difference between P and Q valve tests, although there was a short period of manual control of BPCV during P valve test (Fig.5). This is suspected to be resulted from a difference in the characteristics of those two control valves and/or in the test intial conditions. Finally, Figure 5 shows that the simulation results trace the trends of test data including the stiction phenomena.

(2) -10% step decrease in pressurizer level setpoint

Figures 6, 7, and 8 show the comparison between the simulation and test results for the PZR level, letdown flow, and backpressure, respectively, when the PZR level setpoint is rapidly decreased from 43% to 33%. As shown in Figure 6, for the Q valve test case, the pressurizer level was initially increasing during the first 200 seconds before it started to decrease, although the level setpoint was rapidly decreased. It means that the test was started before the major NSSS parameters reach steady state. This caused the test result to deviate from the simulation result which shows a relatively smaller undershoot in the PZR level (Figure 6) and a smaller variation in the letdown flow (Figure 7) than the test results. However, the simulation results agree well with the P valve test result considering the difference in the initial PZR level. Also, Figure 7 proves the fact that the simulation results match better with P valve test results rather than Q valve test. Since this conclusion is contracdictory to that for the +10% step increase test, it can be concluded that the letdown test is more dependent on the test initial conditions rather than the valve characteristics. Figure 8 shows that the backpressure trend of the simulation result satisfactorily traces the test result. Also, Figures 7 and 8 show that the revised letdown model can predict the stiction phenomena satisfactorily.

(3) -20% ramp decrease with 1%/second rate in pressurizer level setpoint

Figures 9, 10, and 11 compare the simulation results with the Q valve test results when the PZR level setpoint is decreased from 52.6% to 33% at a rate of -1% per second. (The P valve test was not performed for this case.) As shown in these figures, the trends of the simulation results satisfactorily traces the test data and has a smaller undershoot compared to the test result. That is, the revised letdown model showed a slightly faster response compared to the measured test data as was in the aforementioned two test cases. A large undershoot in the letdown flow below the minimum design value of 114 l/min around 2500 seconds is mainly caused by the difference in the valve characteristics between the actual and model.

5.0 Conclusions

The results of the integrated performance test for the YGN 3 CVCS were compared with the simulation results of the modified LTC computer code which revised the CVCS modeling of the current LTC code. The comparison shows that the modified LTC code can predict the transient behavior of letdown system tests very well. Especially, the model was verified to be able to predict the "Stiction" phenomena which caused instantaneous fluctuations in the letdown backpressure and flowrate. Therefore, it is concluded that the modified LTC computer code with the ability of calculating the "Stiction" phenomena will be very useful for future plant design and test predictions.

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Table 1. Control Setpoints for PLCS and Backpressure Control Valve Controller

Parameter	Description	Setpoint
K_1	Gain in PI controller for LCV	3 %/%
τ_1	Integral time constant in PI for LCV	480 seconds
τ_2	Time constant in Lag unit	180 seconds
L_{HI}/L_{LOW}	High/Low limit in Signal Limiter	0.820 / 0.226
P_{set}	Backpressure setpoint for BPCV	460 psig
K_2	Gain in PI controller for BPCV	0.25 %/%
τ_3	Integral time constant in PI controller for BPCV	25 seconds
K_c	Gain in PI controller for CCW CV	0.1 %/%
τ_c	Integral time constant in PI controller for CCW CV	20 seconds

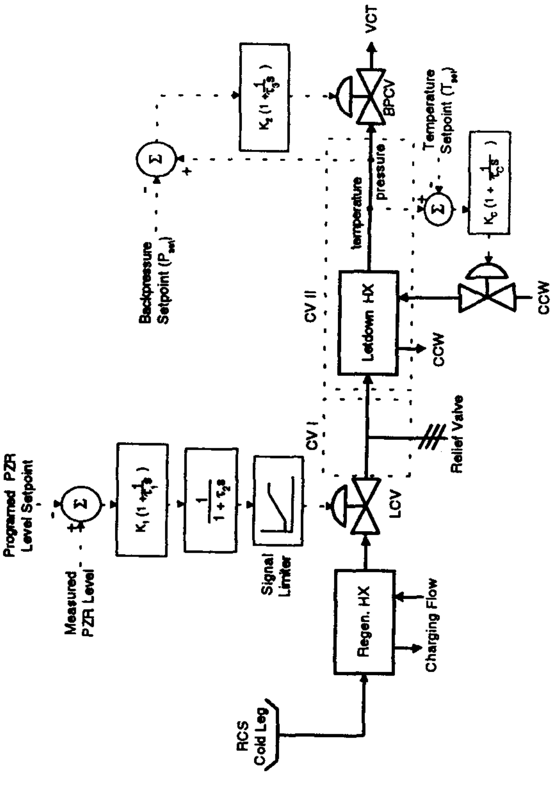

Fig.1 YGN 3 Letdown Line Model

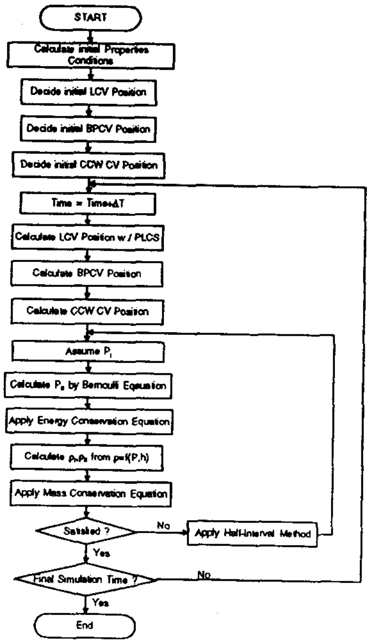

Fig.2 Schematic Flow Chart for Letdown Line Modeling

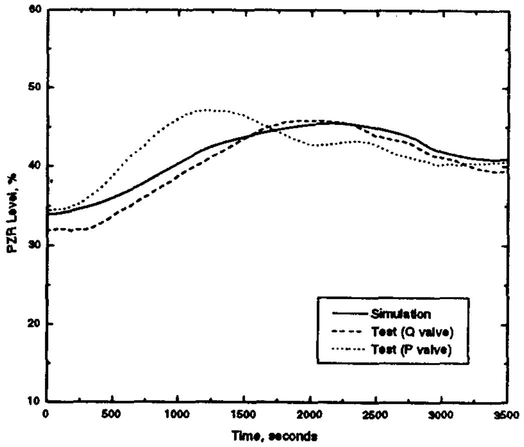

Fig.3 PZR Level during +10% Step Change

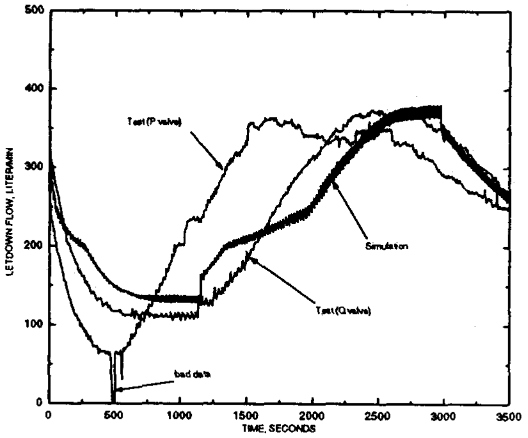

FIG 4. Letdown Flow During +10% Step Change

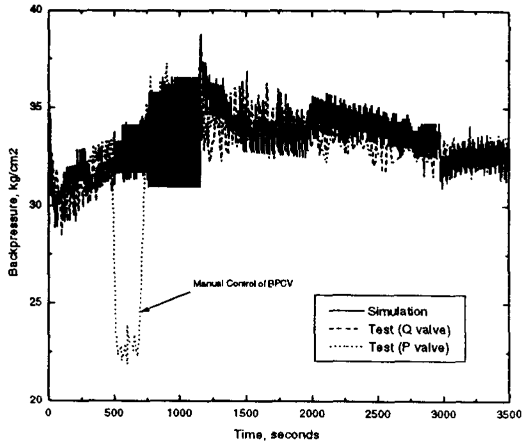

Fig.5 Backpressure during +10% Step Change

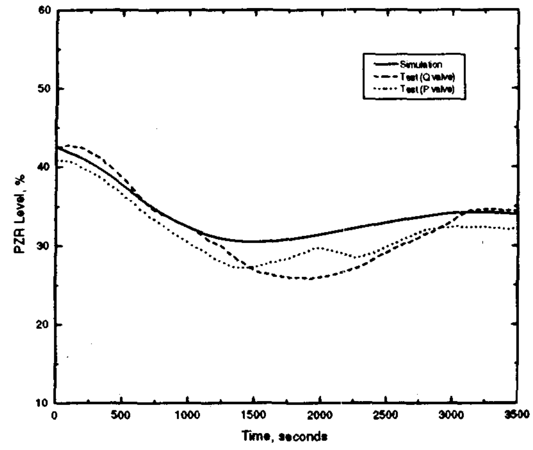

Fig.6 PZR Level during -10% Step Change

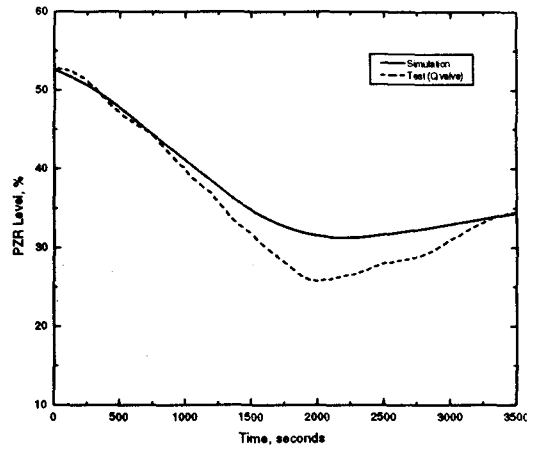

Fig.9 PZR Level during -20% Ramp Change

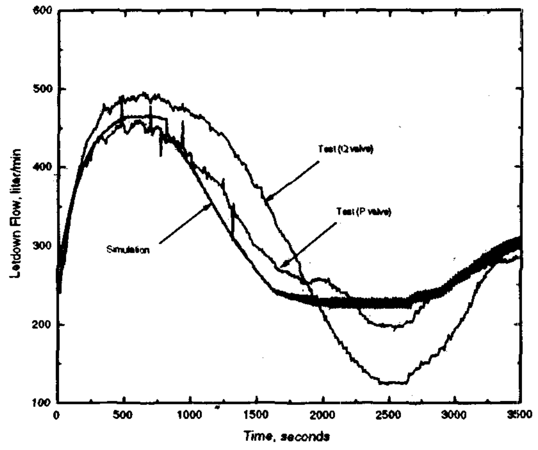

Fig.7 Letdown Flow during -10% Step Change

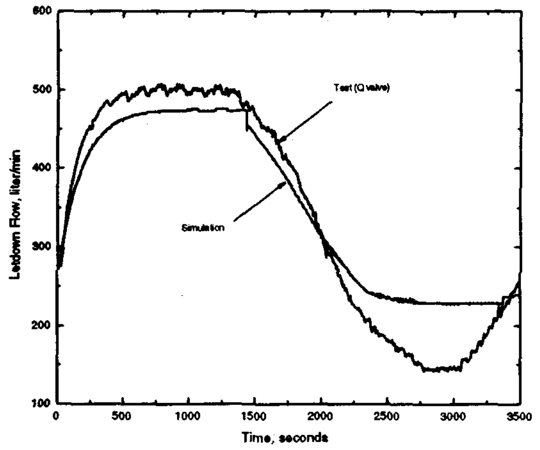

Fig.10 Letdown Flow during -20% Ramp Change

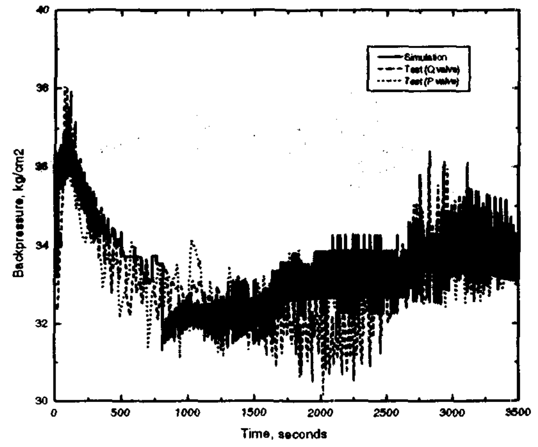

Fig.8 Backpressure during -10% Step Change

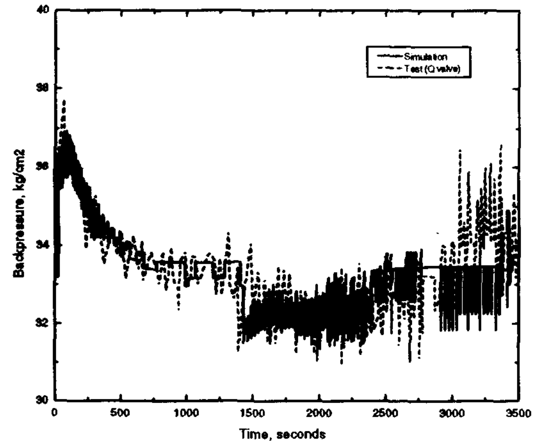

Fig.11 Backpressure during -20% Ramp Change