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Transient Analysis of Letdown System with Letdown Orifices

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ABSTRACT

The CARD(CVCS Analysis for Design) code has been developed for the transient analysis of the letdown and charging system of a nuclear power plant. The code has been verified by comparing the simulated data with the measured data from the performance test of the letdown system with letdown control valves. The simulated data showed good consistency with the plant measured data. Analyzed are the flow and pressure transients in the letdown line with letdown orifices. The sensitivity studies are performed to evaluate the backpressure response and system instability for various valve stroking times, controller control setpoints and valve characteristics. The results show that the backpressure controller control setpoints and letdown orifice isolation valve stroking times have a significant effect on the letdown system stability. It is also found that the worst transient occurs during the minimum flow to normal flow changeover. The results obtained from this study will be used to verify the system design and to select the optimum control parameters for the letdown system having letdown orifices.

1.0 Introduction

The schematic diagram for letdown subsystem of chemical and volume control system(CVCS) of Korea Nuclear Power Plant is shown in Figure 1. Letdown flow from the reactor coolant system(RCS) cold leg passes through the tube side of the regenerative heat exchanger for an initial temperature reduction. The letdown orifices reduce the letdown pressure and are used to obtain the required flowrate. The letdown orifices are placed in or out of service by combinations of letdown orifice isolation valves. The letdown orifice isolation valves are automatically controlled by the Pressurizer Level Control System(PLCS) or manually operated. The required coolant volume in the reactor coolant system is maintained automatically via the PLCS. The PLCS controls letdown orifice isolation valves and regulates the charging flow control valve. The final reduction to the purification subsystem operating temperature and pressure is accomplished by the letdown heat exchanger and letdown backpressure control valve. A backpressure control valve properly maintains the pressure to prevent flashing in the letdown line. The flow then passes through a filter, an ion exchanger, a strainer, and is finally sprayed into the volume control tank. The CARD code has been developed to simulate the thermal-hydraulic performance of the CVCS under dynamic operating conditions[1]. The CARD code establishes steady state and transient conditions with fixed RCS boundary conditions of temperature and pressure.

The CARD code has a modular structure which is composed of generalized standard subroutines for the components such as valves, pumps, orifices and heat exchangers. The computer code has already been verified by comparing with actual test results[1].

The purpose of this study is to investigate the design and control parameter for mitigating and preventing of letdown system transients. Therefore, the analysis focuses on the system transients in the letdown line. The sensitivity studies are carried out to determine the limiting case for letdown operation, the optimal stroking time of letdown orifice isolation valves, and the plug type of letdown isolation and backpressure control valve. The effect of controller setpoint changes is also evaluated.

2.0 Modeling Formulation

2.1 Modeling of Letdown System

The letdown system is modeled as shown in Figure 1. The modeling of the system is based on nodalization and flowpath networking. The letdown system is nodalized into nine normal nodes, three boundary nodes and 17 flowpaths. The regenerative heat exchanger and the letdown heat exchanger are modeled as normal nodes and the letdown nozzle, the volume control tank(VCT) and the equipment drain tank(EDT) are modeled as the boundary nodes. The state parameters such as pressure, temperature and fluid mass are calculated in each node by solving the nodal mass and energy conservation equations, and the flowrates between nodes are calculated by solving the mixture momentum equation in each flowpath. The governing equations are derived based on the assumption of homogeneous equilibrium[2]. The momentum equation is linearized and discretized, and the energy and mass conservation equations are discretized to be solved numerically. The loss coefficient(i. e., flow resistance or K value) at each orifice manifold flowpath is determined by trial and error to keep the balance of pressures in nodes and flowrates in flowpaths for the steady state letdown operation.

2.2 Assumptions in Modeling

Three valve plug types(i.e., quick open, linear, and equal percentage) are considered such as quick open type, linear type and equal percentage type to select optimum plug characteristics of letdown orifice isolation valves and letdown backpressure control valves. The open/close stroking time of relief valve is assumed to be 1 sec in simulating the transient due to the relief valve opening. Also, the valve plug characteristics of relief valve is assumed to be of quick open type. The stiction(sticking friction) effect which is expressed as a percentage of the valve full travel length results from the mechanical friction between the valve stem and the packing and prevents the valve from responding to the demand until the demand signal is larger than the value of stiction. The stiction of letdown backpressure control valves is assumed to be 1.0% .

In this analysis, it is assumed that the charging system is in normal operation during the transient. It is also assumed that the RCS is an infinite water source and VCT is an infinite water sink. The pressurizer level control system(PLCS) is assumed to be in manual mode, that is, the letdown orifice isolation valves and charging flow control valves are controlled manually. The boronometer and process radiation monitor (PRM) flow controllers are not modeled in the code.

3.0 Selection of Limiting Case for Analysis

The boundary conditions for RCS, EDT, and VCT are assumed to be normal operational pressures and normal operational temperatures, except for Case 6 in which the RCS pressure is 1700 psig. The following input data are used to select the limiting case, based on the operation experience of the previous plants.

- The stroking times of letdown orifice isolation valves(CH-110X/Y/Z) are 25 sec.
- The plug type of CH-110X/Y/Z is of linear type.
- The plug type of letdown backpressure control valve(CH-201) is of equal percentage type.
- The control parameters for P-201 are 0.667 for proportional gain and 25 sec for integral time constant.

The following 6 cases are evaluated:

a. Case 1: Zero to minimum letdown flow change (0 gpm $\rightarrow$ 30 gpm)
b. Case 2: Minimum to normal letdown flow change (30 gpm $\rightarrow$ 75 gpm)
c. Case 3: Normal to maximum letdown flow change (75 gpm $\rightarrow$ 135 gpm)
d. Case 4: Maximum to normal letdown flow change (135 gpm $\rightarrow$ 75 gpm)
e. Case 5: Normal to minimum letdown flow change (75 gpm $\rightarrow$ 30 gpm)
f. Case 6: Closing the letdown orifice bypass control valve (CH-200) in heatup operation

The steady state parameters are generated as the initial condition for CARD code run. In generation of steady state parameters, no stiction of letdown backpressure control valve is assumed in order to easily accomplish the steady state.

In order to select the limiting case among 6 cases, the transient of the letdown backpressure is analyzed and possibility of relief valve opening is evaluated. The letdown backpressures for the Cases 1 through 6 are shown in Figure 2. The letdown backpressure controller (P-201) provides high and low alarms at 500 psig and 420 psig, respectively. It is shown in Figure 2 that high alarm setpoint is exceeded for Cases 2 and 3 (flow increment), and low alarm for Cases 4, 5 and 6 (flow decrement). As shown in Figure 2, the Case 2 results in the severest backpressure from the viewpoint of pressure overshoot. After the overshoot is diminished, the backpressure continues oscillating within 5 psi peak-to-peak due to the stiction effects of letdown backpressure control valve.

The highest peak of letdown backpressure is of a concern for Cases 1, 2 and 3 in which the flow increases and the letdown backpressure is built up, because the high pressure above the letdown relief valve setpoint can open CH-345 and result in very severe transients. As shown in Figure 2, Case 1 shows no pressure peak, and Cases 2 and 3 result in higher pressure peaks of 586 psig and 556 psig, respectively.

Since the highest pressure is 586 psig in Node 4 for Case 2 and the opening setpoint of CH-345 is 600 psig, the pressure margin is only very small. Even though CH-345 does not open, the chattering of CH-345 is expected. Therefore, the Case 2 is selected as the limiting case for evaluation of the letdown system performance.

4.0 Sensitivity Analysis

4.1 Optimum Stroking Time of Letdown Orifice Isolation Valves

The boundary conditions and main input data used to determine the optimum stroking time of the letdown orifice isolation valves(CH-110X/Y/Z) are the same as those in Section 3.0, except for stroking time of CH-110X/Y/Z which is to be determined in this section. The following 5 cases are selected for the stroking time.

a. Case A1: CH-110X/Y/Z stroking time = 5 sec
b. Case A2: CH-110X/Y/Z stroking time = 15 sec
c. Case A3: CH-110X/Y/Z stroking time = 25 sec
d. Case A4: CH-110X/Y/Z stroking time = 40 sec
e. Case A5: CH-110X/Y/Z stroking time = 60 sec

For the above cases, minimum to normal letdown transient is evaluated as well. CH-110Y is manually opened in each case. The letdown backpressures for these case runs are shown in Figure 3. It is shown that letdown backpressure controller (P-201) generates high alarm for all cases, and low alarm for

Cases A1 and A2. In Cases A1 and A2, the letdown backpressure cannot be controlled within 460±10 psig and CH-345 opens and chattering occurs, thus the stroking time of 5 sec or 15 sec is not acceptable. For Cases A3 to A5 the letdown relief valve (CH-345) does not open. As shown above, the 25 - 60 sec is acceptable for the stroking time of CH-110X/Y/Z. But, for stroking time greater than 25 sec, changes in the stroking times have little influence on the overall stability of backpressure control.

4.2 Evaluation of Plug Type of Letdown Orifice Isolation Valves

The boundary conditions and main input data used to evaluate the plug type of the letdown orifice isolation valves (CH-110X/Y/Z) are the same as those in Section 3.0. As described in Section 4.1, 30 sec is used for the stroking time of CH-110X/Y/Z. The following 3 cases are evaluated:

a. Case B1: CH-110X/Y/Z plug type: quick open type
b. Case B2: CH-110X/Y/Z plug type: linear type
c. Case B3: CH-110X/Y/Z plug type: equal percentage type

For the above cases, minimum to normal letdown transient is evaluated as well. In each case, CH-110Y is also manually opened with the stroking time of 30 sec. The letdown backpressures for these case runs are shown in Figure 4. For all cases, letdown backpressure controller generates high alarm, but the letdown relief valve does not open. The peak pressure of Case B1 or B2 is smaller than that of Case B3. The control time of Case B2 is about 5 sec less than that of Case B1.From the results, the linear type is preferable as the plug type of letdown orifice isolation valves (CH-110X/Y/Z) in the viewpoint of the letdown backpressure control stability and the peak pressure.

4.3 Evaluation of Plug Type of Letdown Backpressure Control Valve

The boundary conditions and main input data used to evaluate the plug type of letdown backpressure control valves(CH-201) are the same as those in Section 3.0. As concluded in Section 4.2, the plug type of CH-110X/Y/Z is of linear type.

The following 3 cases are evaluated:

a.Case C1: CH-201 plug type : quick open type
b.Case C2: CH-201 plug type : linear type
c.Case C3: CH-201 plug type : equal percentage type

For all cases, minimum to normal letdown transient is evaluated. In each case, CH-110Y is also manually opened with stroking time of 30 sec. The letdown backpressures for these case runs are shown in Figure 5. For Case C1, the letdown relief valve(CH-345) opens and the backpressure oscillates continuously, i.e., the chattering of CH-345 occurs. For Case C2, the backpressure reaches a peak value of 573 psig and returns to the setpoint in approximately 170 seconds after transient. The peak pressure of Case C2 (573 psig) is higher than that of Case C3 (565 psig).

From the results, the controllability and peak pressure of equal percentage type letdown backpressure control valves(CH-201) are almost the same as those of linear type. Therefore, the equal percentage type and linear type are acceptable as the plug type of letdown orifice isolation valves (CH-110X/Y/Z) in the viewpoint of the letdown backpressure control stability and the peak pressure.

4.4 Determination of Optimum Control Parameters for Letdown Backpressure Controller

The boundary conditions and main input data used to determine the optimum control parameters, i.e., proportional gain(PG) and integral time constant(ITC), of the letdown backpressure controller(P-201) are the same as those in Section 4.3, except for the control parameters of P-201 which are to be determined in this section. As recommended in Section 4.3, equal percentage type is used for the plug type of letdown backpressure control valve. The following 4 cases are evaluated:

a. Case D1: PG = 0.2 and ITC = 0.3 sec
b. Case D2: PG = 0.2 and ITC = 40.0 sec
c. Case D3: PG = 3.0 and ITC = 0.3 sec
d. Case D4: PG = 3.0 and ITC = 40.0 sec

For the above cases, minimum to normal letdown transient is evaluated. To determine the acceptability of P-201 control parameters, the following criteria are applied:

a. The letdown relief valve (CH-345) shall not open
b. The letdown backpressure disturbance shall be mitigated within 20 psi peak-to-peak .

The letdown backpressures for these case runs are shown in Figure 6. For Case D1, CH-345 does not open and the backpressure is smoothly stabilized, however 15 to 18 psi oscillations appear sporadically in the trace due to the effects of stiction. For Case D2, CH-345 opens and P-201 cannot mitigate the disturbance within 20 psi peak-to-peak. For Cases D3 and D4, CH-345 does not open, but P-201 cannot mitigate the disturbance within 20 psi peak-to-peak due to backpressure control instability. Only Case D1 is, therefore, acceptable as a means of avoiding the possibility of such oscillation which results in control problems.

For detailed evaluation additional case runs are performed for 0.2, 0.667, 1.5 and 3.0 for proportional gain and 0.3, 10, 25 and 40 sec for integral time constant. The acceptable combination of the proportional gain and integral time constant is presented in Figure 7. The combination of the optimum control setpoints of the letdown backpressure controller can be obtained from Figure 7. P-201 with 0.667 for proportional gain can mitigate the transient for any integral time constant. But P-201 with 3.0 for proportional gain cannot mitigate the transient for any integral time constant.

As shown in Figure 7, it can be concluded that the optimum control parameters are 0.2 or 0.667 for proportional gain and 0.3 sec for integral time constant, and 0.667 or 1.5 for proportional gain and 10 to 40 sec for integral time constant.

5.0 Conclusions

In this paper, the analysis focuses on the system transients in the letdown line. Letdown system design affects transient behavior directly. So, the sensitivity studies are carried out to determine the limiting case for letdown operation, the optimum stroking time of letdown orifice isolation valves, and the plug type of letdown isolation valve and letdown backpressure control valve.

The results show that the backpressure controller control setpoints and letdown orifice isolation valve stroking times have a significant effect on the letdown system stability. It is found that the worst transient occurs during the minimum flow to normal flow changeover. The optimum stroking time of the letdown orifice isolation valves is 25-60 sec. Letdown orifice isolation valves of linear type show more stable controllability than equal percentage type. The controllability of equal percentage type of backpressure control valve is almost the same as that of the linear type. The combination of the optimum control setpoints of the letdown backpressure controller can be obtained from Figure 7.

6.0 References

1. S. W. Kim and J. S.Ahn, "Development of the CARD Computer Code for the Application to the Design of the CVCS in YGN 5&6", KOPEC, Feb. 1998.

2. R. T. Lahey, Jr. and F. J. Moody, "The Thermal Hydraulics of a Boiling Water Nuclear Reactor", ANS/AEC Monograph Series on Nuclear Science and Technology, ANS, 1977.

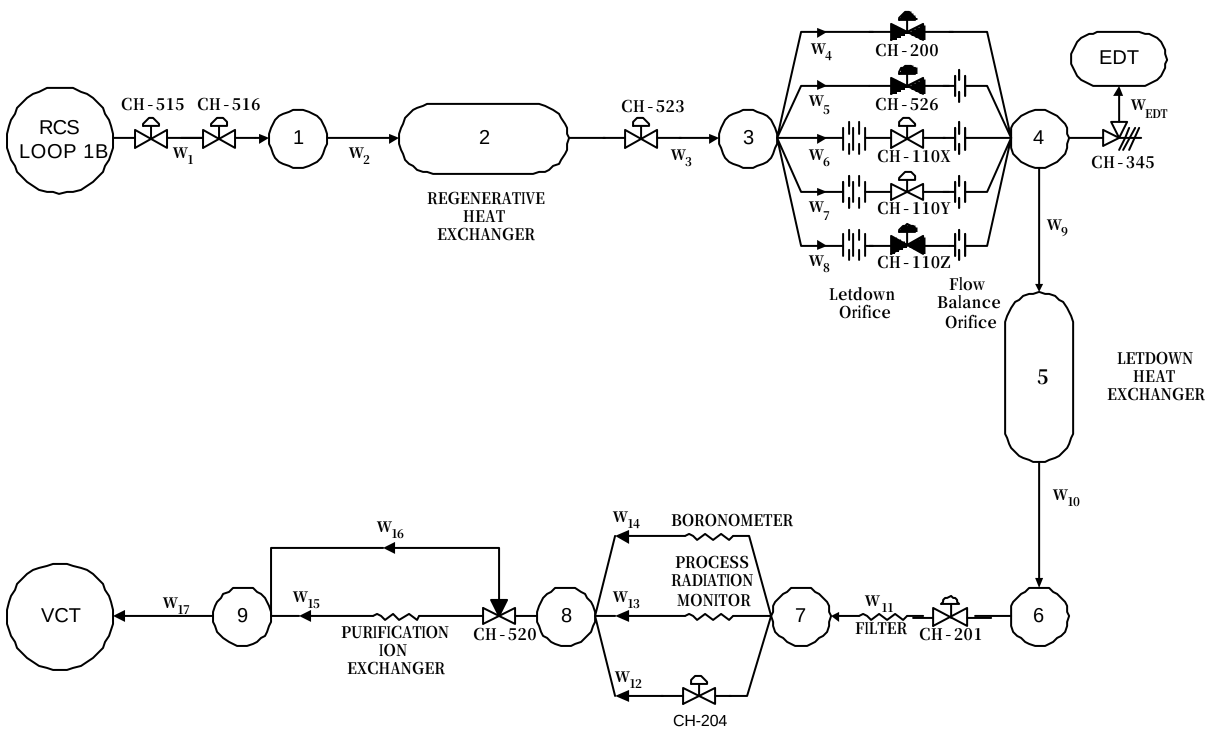


Figure 1. Letdown System Nodalization

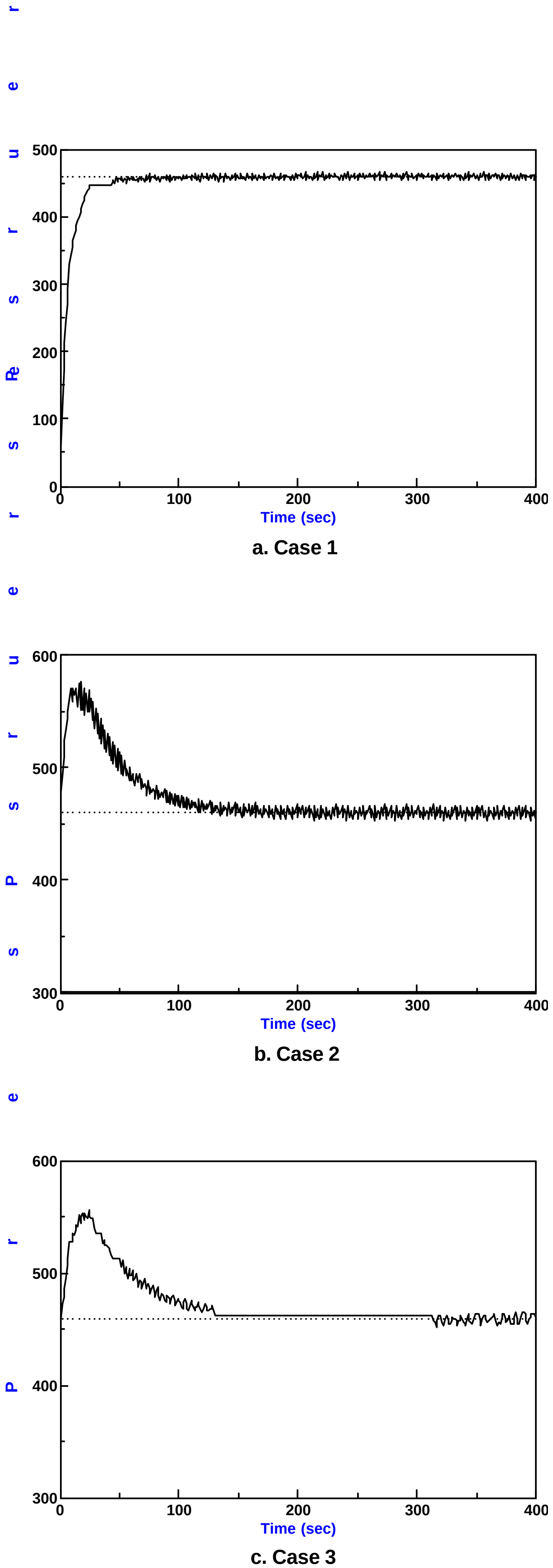


Figure 2. Letdown Backpressure for Limiting Case Selection

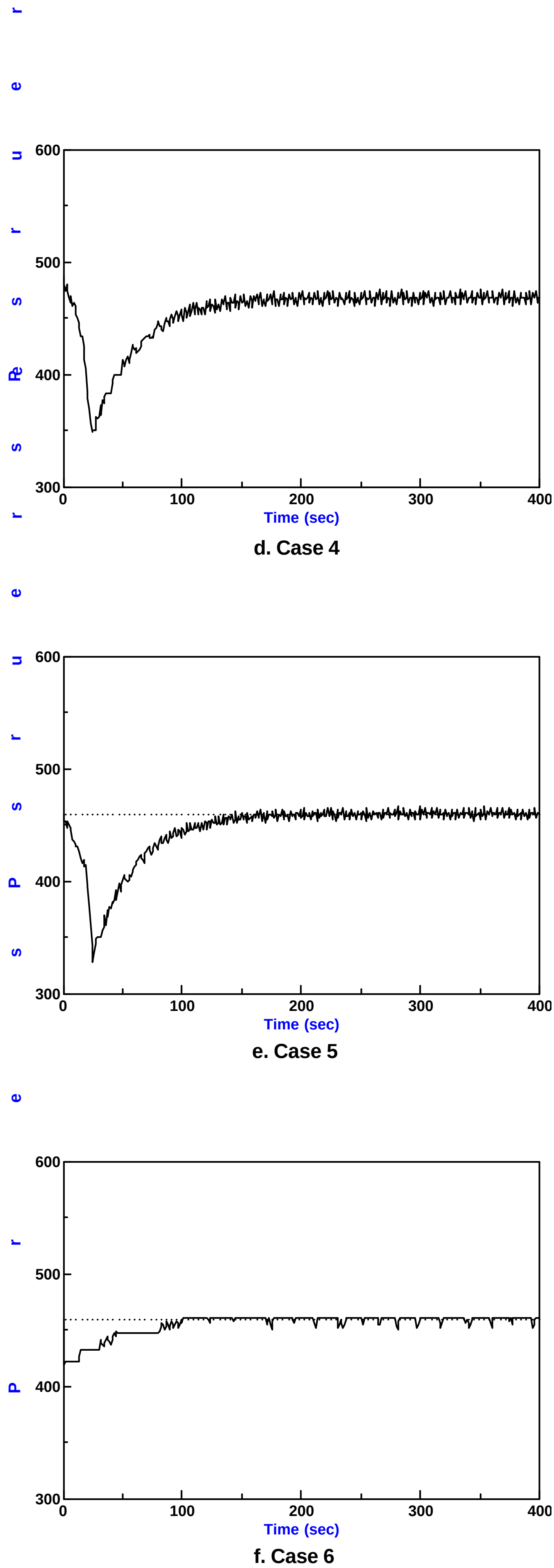
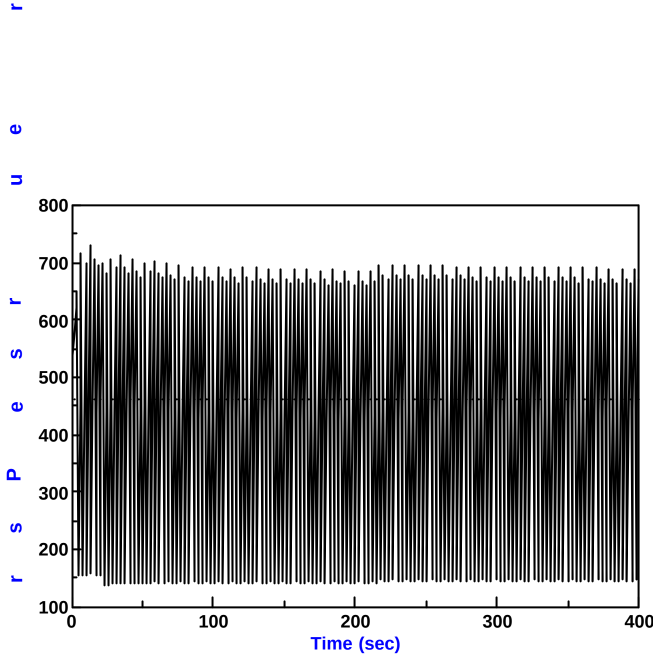
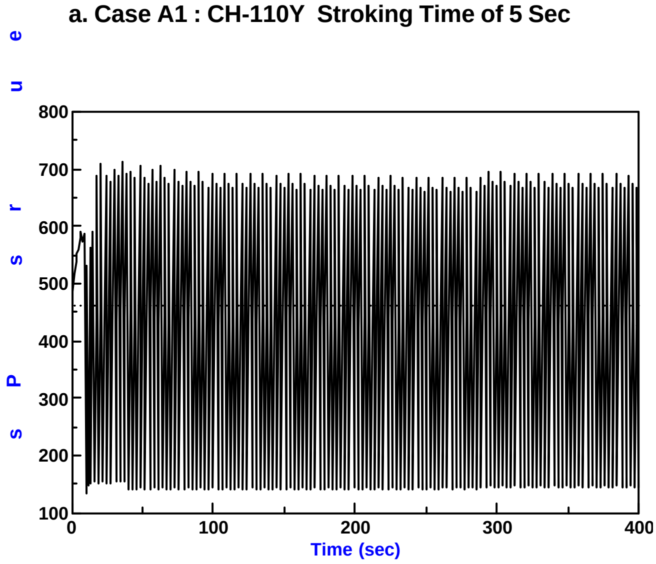


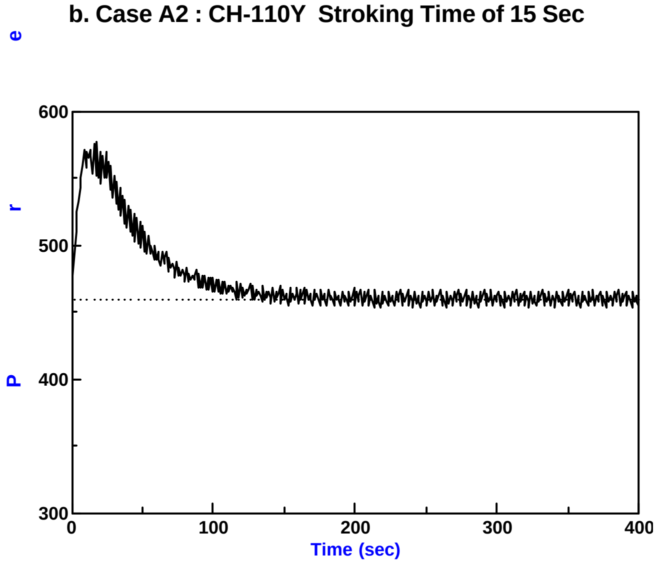
Figure 2 (Continued). Letdown Backpressure for Limiting Case Selection



a. Case A1 : CH-110Y Stroking Time of 5 Sec

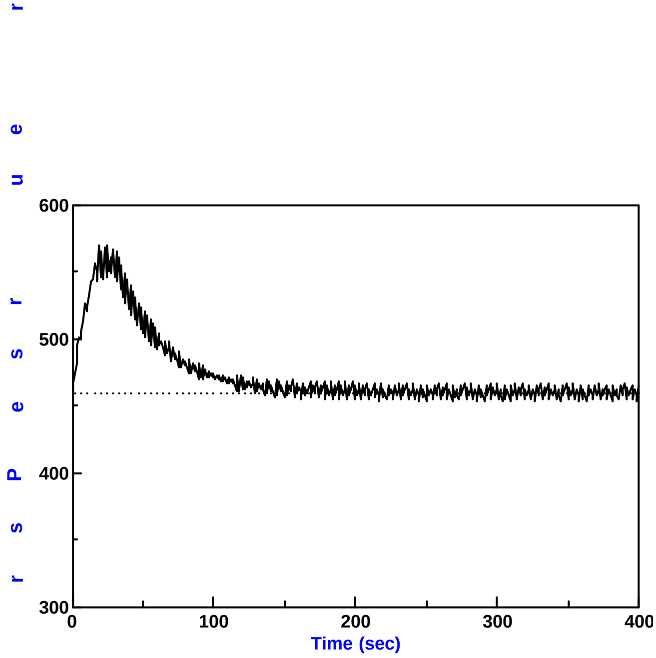


b. Case A2 : CH-110Y Stroking Time of 15 Sec

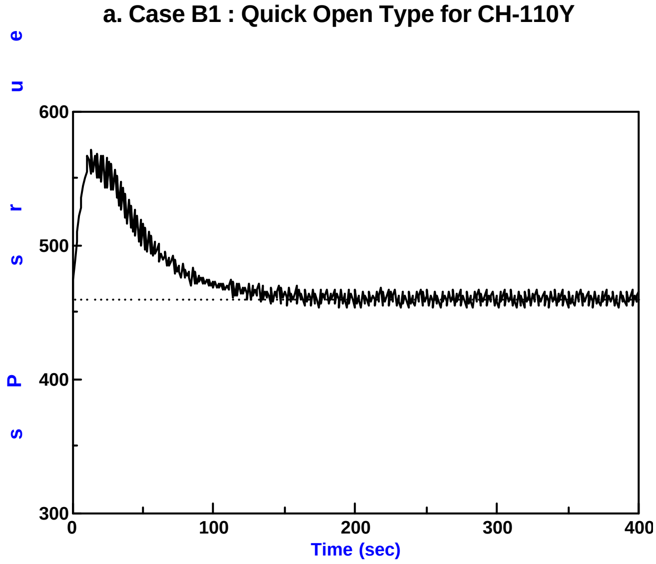


c. Case A3 : CH-110Y Stroking Time of 25 Sec

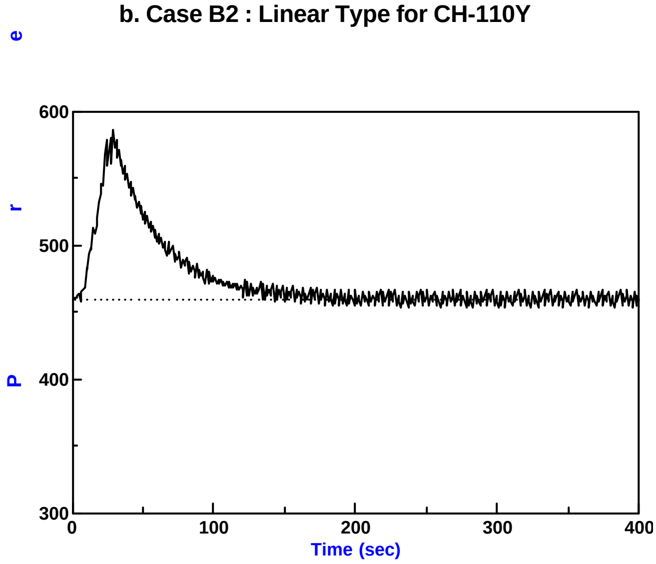
Figure 3. Letdown Backpressure for Determination of CH-110X/Y/Z Optimum Stroking Time



a. Case B1 : Quick Open Type for CH-110Y

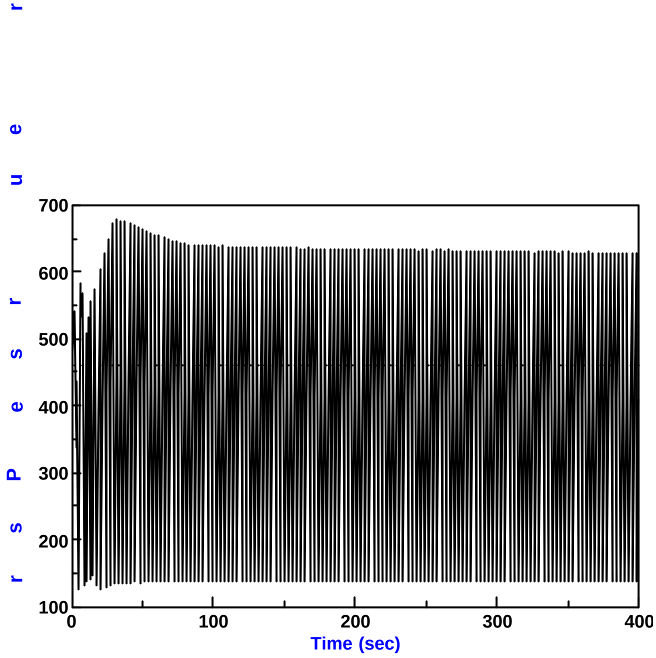


b. Case B2 : Linear Type for CH-110Y

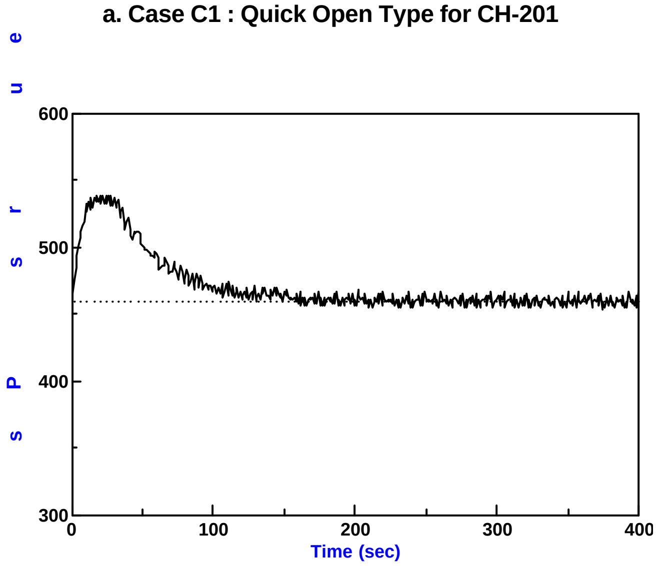


c. Case B3 : Equal Percentage Type for CH-110Y

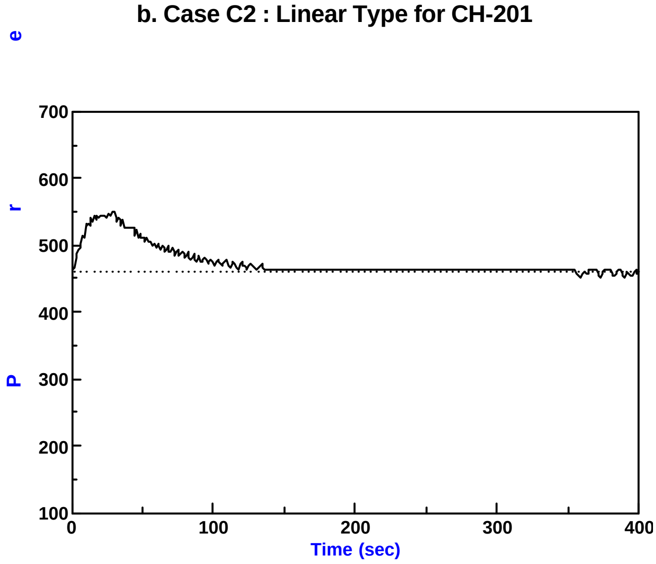
Figure 4 Letdown Backpressure for CH-110X/Y/Z Plug Type



a. Case C1 : Quick Open Type for CH-201

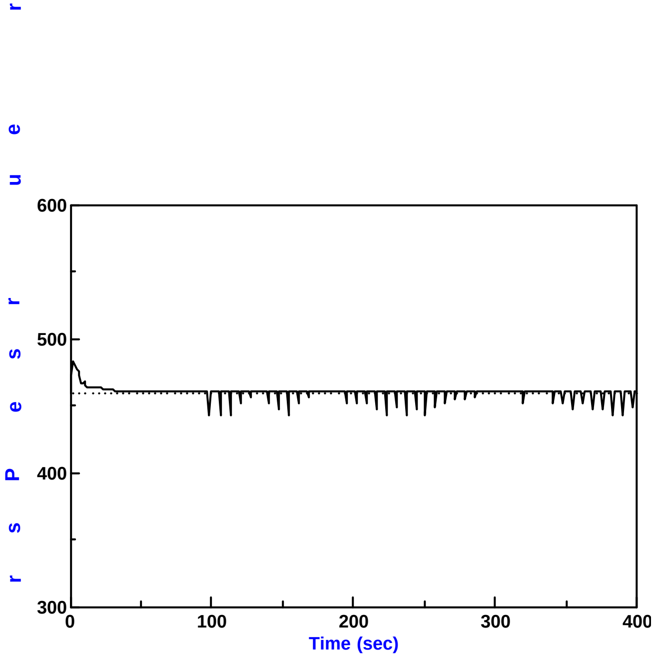


b. Case C2 : Linear Type for CH-201

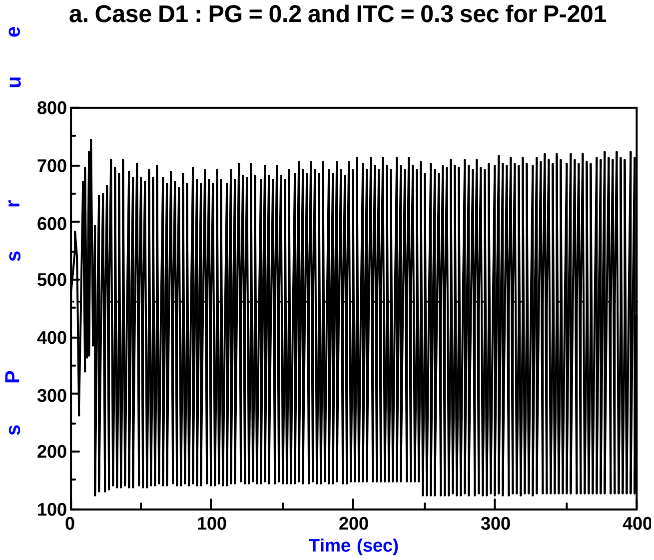


c. Case C3 : Equal Percentage Type for CH-201

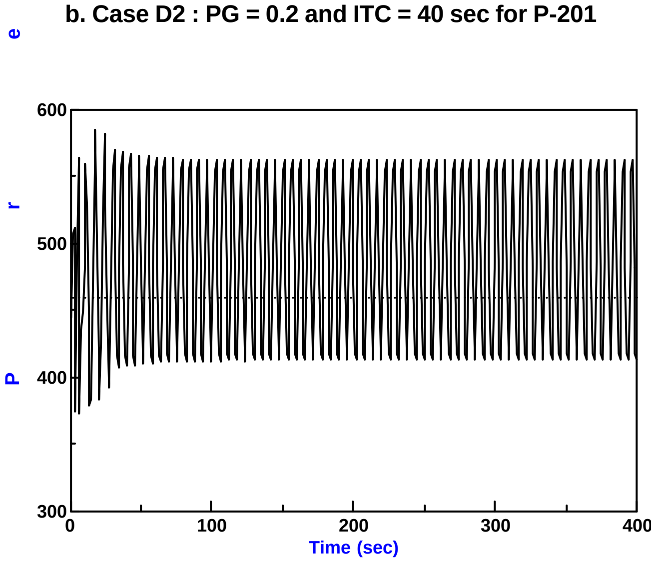
Figure 5. Letdown Backpressure for Evaluation of Letdown Backpressure Control Valve Plug Type



a. Case D1 : PG = 0.2 and ITC = 0.3 sec for P-201

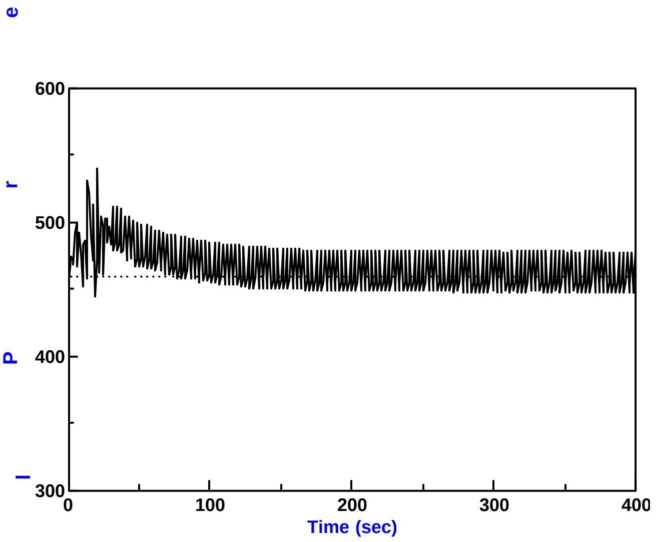


b. Case D2 : PG = 0.2 and ITC = 40 sec for P-201



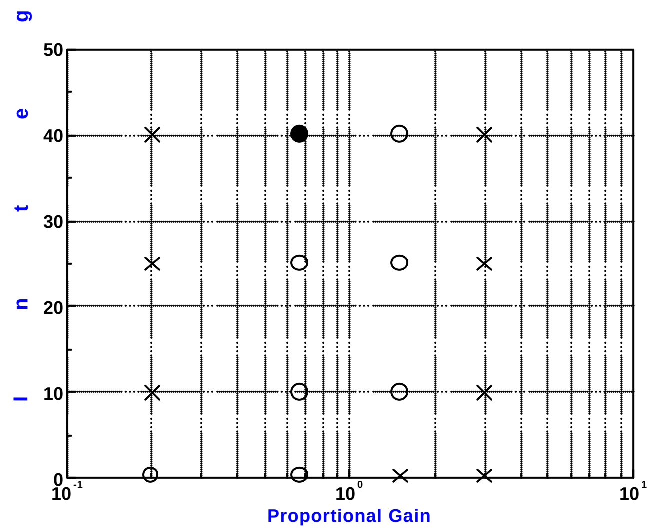
c. Case D3 : PG = 3.0 and ITC = 0.3 sec for P-201

Figure 6. Letdown Backpressure for Determination of Optimum P-201 Control Parameters.



d. Case D4 : PG = 3.0 and ITC = 40 sec for P-201

Figure 6(Continued). Letdown Backpressure for determination of Optimum P-201 Control Parameters.



O : Acceptable X : Not Acceptable

● : Acceptable but chattering expected.

Figure 7. Evaluation Results of P-201 Parameters