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600MW(e) CANDU PHTS Flow Instability and Interconnect Effect

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600 MW(e)급 CANDU형 원자로 1차 열전달계통의 유동 불안정성 및 Interconnect 효과

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Abstract

600 MW(e) CANDU Primary Heat Transport System(PHTS) is composed of the two "figure-of-eight" loops and is designed to operate with the 4% Reactor Outlet Header (ROH) quality at its rated power. This existence of the two compressible regions and the positive flow-quality-void feedbacks are the sources of the PHTS flow instability. To ensure the PHTS stability, ROH-ROH interconnect pipes are installed as passive systems.

This paper describes the investigation of the PHTS flow instability at its design full power condition. Also studied are the interconnect effect and the inherent system damping effect on the system stability. The time domain stability analyses are accessed by using the ATHER/MOD-I code which is the improved version of the KAERI developed ATHER code.

Under the most adverse system modelling, the "figure-of-eight" symmetric loop shows divergent flow oscillations. Under with the interconnect, the PHTS stability is remarkably enhanced so that the system becomes stable. However, even under the conservative pressurizer modelling, the PHTS shows the more convergent flow oscillations. With the interconnect and the pressurizer modelling, its stability is highly creditted. Conclusively, the inherent system damping by pressurizer itself can credit the PHTS stability without the interconnect.

요 약

600 MW(e)급 CANDU형 원자로의 1차 냉각재계통은 2개의 "8자" 모양 루프로 구성되며 정상운전중 원자로 출구헤더(ROH)의 설계 quality는 4%이다. 이러한 루프내 2부분에 압축성 유체의 존재 및 유동-quality-기포율의 정궤환 효과는 1차 냉각재계통 유동 불안정의 주요인이 된다. 계통의 안정을

위하여 설계 변경사항으로서 같은 루프의 ROH-ROH간 interconnect가 설치되었다.

본 논문은 정상운전시 1차 냉각재계통의 유동 불안정현상을 조사연구하며, 또한 interconnect가 유동 안정성에 미치는 영향 및 계통 고유의 유동 안정성에 대한 연구를 수행한다. 시간 영역의 안정성 분석은 ATHER코드로부터 보완된 ATHER/MOD-I코드를 사용하여 분석한다.

가장 보수적인 계통 모형, 즉 대칭형 루프의 유동은 발산하며, interconnect를 설치함으로써 계통의 유동 안정성은 크게 향상되어 안정된다. 그러나 보수적인 가압기 모델을 사용 분석하였을 경우라도 계통의 유동 안정성은 보장됨을 알 수 있다. 실제적인 계통 즉 가압기와 interconnect를 모사한 경우의 계통 안정성은 크게 보장된다. 결론적으로 비록 interconnect는 계통의 안정성을 크게 향상시키나 가압기 등 계통 고유의 유동 안정성은 매우 커서 interconnect가 설치되지 않았더라도 1차 냉각재 계통의 유동 안정성을 보장함을 알 수 있다.

I. Introduction

600 MW(e) CANDU PHTS composed of two "figure-of-eight" loops is designed to operate with the 4% ROH quality at its rated power[1]. This existence of two compressible regions in a PHTS loop and the positive flow-quality-void feedback effect are the major sources of the PHTS flow instability under the asymmetric perturbations which can occur during normal operations. Since the gain of the flow-quality-void feedback at low quality regions[2] is large enough that the once disturbed system will continue to tilt to one side until some other nonlinear effects limit further tilting, that is, until it is balanced by the friational dissipation. And the speeds of the void propagation and the feedback process are slow enough such that the gross floow interchanges the high and low velocity regions before the complete collapse of void. Although the pumps and the steam generators counteract to the flow and the void respectively, the PHTS is designed to minimize the hydraulic losses[3], which are sources of the system damping, so that it is susceptible to the flow instability phenomena. Such flow instability phenomena may develop to the self-excited oscillations if not for any regulatory or protective system actions and, if oscillations are undetermined, may lead to fuel damage. To ensure the stability of the PHTS, ROH-ROH interconnect pipes[3] are installed as passive systems linking two compressible regions of the same loop, even though the inherent system dampings such as pressurizer surge, pump flow controls, parallel fuel channels and turbulent-diffusive mixing at headers are thought to essentially increase the system stability.

This work describes the investigation of the 600 MW(e) CANDU PHTS flow instability at its design full power, including the interconnect pipe effect on enhancing the system stability and the effect of the inherent system damping on the system stability. Also studied are the real system responses with the interconnect and including the pressurizer modeling.

To access the PHTS flow instability problems, the time-domain stability analysis code, ATHER/MOD-I,[4] is improved from the KAERI developed ATHER code.[5] The PHTS is one-dimensionally nodalized into 106 nodes and 107 links and the heavy water properties are used for the analysis. Various system effects are simulated by opening and closing the control valves at related links and a conservative pressurizer model is adopted. Reactor process trips are removed for the development of flow oscillations.

Initiating perturbation for the stability analysis, standard perturbation, is selected to be the mass extraction of 200 Kg/s directly from a ROH for 5 seconds with its time varying enthalpy. The system initial status is selected to be numerically stable before imposing the standard perturbation. And the degree of the stability is measured by the maximum overshoot and the settling time.[6]

The results show that the PHTS stability is creditted either with the interconnect or even with the conservative pressurizer modelling, even though the "figure-of-eight" symmetric PHTS shows divergent flow oscillations.

II. ATHER/MOD-I Models and Improvements[4]

The ATHER/MOD-I code is the improved version of the KAERI developed ATHER code which is primarily developed for the large LOCA analyses. The ATHER/MOD-I code has the capability to solve the various two-phase flow problems by providing various boundary conditions and control logics. These boundary conditions and control logics are coupled with the fluid flow conservation equations and heat conduction equation to form the governing equation for the system to be analyzed.[18] In hydraulic calculations, an implicit numerical integration technique[7] is used to solve the one dimensional flow conservation equations - mass, energy and momentum equations - together with the equation of state. The two phase fluid is assumed to be both homogeneous and in thermal equilibrium. However, the slip and drift corrections are used to account for the relative phase motions.[8],[9] In thermal calculations, an one-dimensional heat conduction equation is solved implicitly with the reactor power variations to be coupled with hydraulic calculations explicitly. And the various state-of-the-art correlations are provided as constitutive equations. To access the stability problems, the ATHER/MOD-I code is improved to have the capability of conducting the stability analysis. The improvements include the heavy water properties, the pressurizer model, the state-of-the-art two phase friction multiplier of Ontario-Hydro's,[10] drift-flux corrections on mass and energy equations and on the liquid mass flow rate solving routines. And the various constitutive correlations are implemented for the application of the heavy water properties. The nodalization capability of the ATHER code is increased from 70 to 150 nodes and links in the ATHER/MOD-I code for the fine nodalization of the stability analysis.

This improved version is operable on CDC Cyber 174-16 and it takes about 2.5 CP seconds for 1 time step simulation with 106 nodes and 107 links nodalization. Environmental programs developed for the stability analysis are "D_2O"[11] for the heavy water steam table generation and "BULPLT"[12] for plotting file generation for CALCOM Plotter.

II-1. D_2O Steam Properties

The D_2O thermodynamic properties are obtained by combining the D_2O equation of state[13] and the D_2O saturated vapour pressure equation.[14] The D_2O equation of state represents a continuity of the single phase states covering both liquid and vapour regions from tripple point to about 100 MPa in pressure and 600°C in temperature. The D_2O saturated pressure equation predicts the pressure as a function of temperature within 0.02% uncertainty.

Since the equation of state is a function of density and temperature, the density must be obtained first by combining the above two equations for the given pressure and temperature. Numerical method used to find the density is the Newton-Raphson Method[15] with the solution convergence limit of 10^{-9}. For the given temperature and pressure and with this calculated density, all thermodynamic properties of the heavy water such as specific enthalpy, specific internal energy and specific heat for the subcooled liquid and the superheated steam including the saturation line are obtained by differentiating the equation of state.

Also required values are property partial derivatives of the heavy water, since the ATHER/MOD-I code estimates the pressure increment as a function of mass and energy increments and the property derivatives.[4] The required property derivatives are $(\partial P/\partial M)_{\bar{U}}$ and $(\partial P/\partial \bar{U})_M$. These values are obtained as follows, which are derived from the equation of partial derivatives.

$$(\partial P/\partial \bar{U})_M = (\partial P/\partial T)_\rho \frac{1}{M} (\partial T/\partial u)_\rho$$

$$(\partial P/\partial M)_{\bar{U}} = \frac{1}{1000V} (\partial P/\partial \rho)_T - (\partial P/\partial \bar{U})_M \times [u + \rho(\partial u/\partial \rho)_T]$$

where

V : volume, m^3

ρ : density, g/cm^3

M : mass, Kg

$\bar{U}$: internal energy, KJ

P : pressure, MPa

u : specific internal energy, KJ/Kg

T : absolute thermodynamic temperature, °K

The environmental program, "D_2O"[11], for generating the D_2O steam table and property derivatives table is developed in which the range of table size is controlled. And the three-dimensional searching-interpolating routines of the tables are implemented in the ATHER/MOD-I code. The transport properties of the heavy water such as thermal conductivity and viscosity are selected from the references[16],[17]

II-2. Pressurizer Model

The two PHTS loops are intereconnected by the pressurizer linking one of ROH's at each loop. In this modelling, any control or protective system actions are not creditted for the conservatism. Mass and energy conservation equations governing the mathematical modeling are given as;

$$dM/dt = W_{surge} - W_s$$

$$d(Mh)/dt = W_{surge}h_{surge} - W_s h_s$$

where

W_{surge}, h_{surge}; mass flow rate and enthalpy of surge flow

W_s, h_s; mass flow rate and enthalpy of steam flow

The pressurizer pressure transients are predicted under the assumption of the isentropic compression of steam volume for the insurge flow and the thermal equilibrium model for the outsurge flow.[16] The isentropic compression model for the insurge flow assumes the coexistence of the subcooled liquid and the superheated steam with no heat transfer neither between phases nor between the walls. The steam pressure is represented as;

$$P_i = P_{i-1}((v_g)_{i-1}/(v_g)_i)^\nu$$

where the subscript i means present time step and $(i-1)$ means previous time step

v_g; specific volume of steam

ν ; polytropic exponent $(C_p/C_v = 1.27)$

The thermal equilibrium model for the outsurge flow is based on the assumptions of the instantaneous flashing and condensation between phases. In this model, the pressure transients are obtained by the iterative procedure of searching the saturation line in the steam table.

Then, together with the thermodynamic properties of pressurizer, the water level in the pressurizer is obtained.

III. Interconnect[3]

Two compressible regions, ROH's, of the same loop are interconnected to ensure the stability of the PHTS by transmitting the driving forces for the liquid velocity of the perturbed ROH to another ROH.

The design concepts of the interconnect are (1) the maximum stabilizing effect and (2) the maximum flow component in phase with the pressure oscillations between ROH's. The pressure drop through the interconnect pipe is composed of two terms of inductive and resistive components as;

$$\Delta P = \underbrace{I(dW/dt)}_{\text{inductance}} + \underbrace{K(W^2/2\rho A^2)}_{\text{resistance}}$$

where

ΔP : interconnect pressure drop

W : interconnect flow rate

A : flow area

K : loss coefficient

I : inertia ($=L/A$)

The interconnect is designed to have the inductance as low as possible and the resistance as high as possible. The selected diameter of the interconnect is 6 inches with considering the item (1) above and the other constraints. And the restriction orifices of $K=41$ per each are installed at both ends of the interconnect pipe to make the resistive component be equal or greater than the inductive component (item (2)).

To utilize the steam cushion effect which is the most effective mode for the stabiliy control, the interconnect is elevated up above the ROH's.

IV. Tests and Results

IV-1. Analytic Methods and Models

The PHTS is one-dimensionally nodalized into 106 nodes and 107 links which include the pressurizer, steam generators, pumps, the interconnect, the other loop and the average core passes which represent 95 fuel channels and feeder pipes as shown in figure 1. Each component is equipped with control valves and its effect is simulated by opening and closing the control valves at related links.

The conservative pressurizer model is implemented in the code and it works as a pressure-enthalpy boundary condition throughout the transients. The pressurizer is modelled to be linked to the ROH node 67 far from the perturbation and the other loop effect, which can damp out system oscillations by surging to and from ROH of the other loop is ignored for the further conservatism.

The PHTS is assumed to be at the design quality of 4% at ROH at its rated power. An average fuel channel is nodalized into 10 nodes with the distributed power shape of cosine. Two phase regions of the PHTS are divided into the fine node structure to consider the dynamic effect

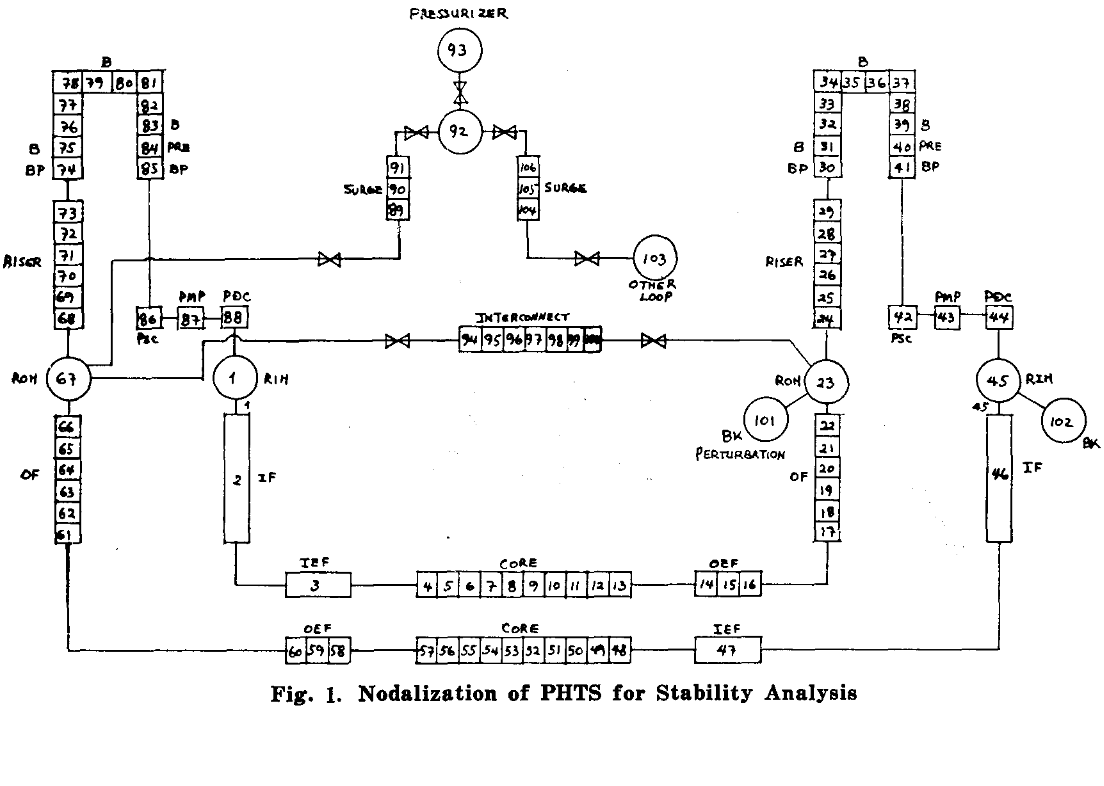

Fig. 1. Nodalization of PHTS for Stability Analysis

more precisely. And the reactor process trips are removed for the development of the oscillation.

The primary to secondary heat transfer through the steam generator tubes is modelled as having the constant steam generator tube outer wall heat transfer coefficients and the constant secondary side temperature throughout the transients. And the tube inner surface heat transfer coefficients are calculated according to the primary side coolant conditions. The heat slab calculations are performed only at the fuel rods and the steam generator tubes. The pump model is selected from the ANC pump model adjusted by the fully degraded two phase pump data.[1]

The heavy water properties (static and transport properties) are used and the state-of-the-art Ontario-Hydro's two phase friction multiplier is used. The Bryce slip model[8] and the RELAP-UK drift model[9] are selected to account for relative phase motions.

The initiating perturbation for the stability analysis, standard perturbation, is selected to be the mass extraction of 200 Kg/sec directly from a ROH for 5 seconds with the time-varying ROH enthalpy. This perturbation is modelled in the code as a flow-enthalpy boundary condition at ROH node 23. And the degree of the PHTS stability is measured by the maximum overshoot and the settling time.[6]

The system initial status is selected to be numerically stable before imposing the standard perturbation. Since the finer nodalization to get the more precise system response produces the numerical instability due to the spatial convergence problem, the adjustment of the code numerical scheme is required. The chosen method is the smoothing of the property partial derivatives, $(\partial P/\partial M)_{\bar{U}}$ and $(\partial P/\partial \bar{U})_M$, between phases. With this method, the numerical stability is achieved by reducing the pressure-flow-pressure feedbacks. The obtained initial status of the PHTS is listed in Table 1. The interconnect is assumed to contain the two phase fluid at its initial state.

The cases for the stability analysis are classified into 5 cases such as shown in Table 2. Each component effect is simulated by opening and closing the control valves as shown in figure 2. These case studies are selected to investigate the "figure-of-eight" symmetric system flow instability phenomena, the effect of the interconnect pipe on enhancing the PHTS stability and the inherent system damping effect by using the conservative pressurizer modeling. The close approach to the real PHTS behavior with the interconnect and including the pressurizer modeling is

Table 1. Initial Steady State of PHTS

—Thermal Power:	full power
—System Flowrate:	4151 lb/sec
—RIH Temperature:	511°F
—RIH Pressure:	1645.1 psia
—ROH Temperature:	590°F
—ROH Pressure:	1449 psia
—ROH Quality:	3.86%
—Pressurizer Level:	41 ft
—Smoothing Parameter:	Xs=0.13

Table 2. Classification of Case Studies

	Cases	CV1	CV2	CV3	CV4	CV5	Remarks
1	H_2O with Symmetric System	off	off	off	off	off	Code Verification
2	D_2O with Symmetric System	off	off	off	off	off	Investigation of Flow Instability
3	D_2O with I/C	on	on	off	off	off	Test I/C Effect
4	D_2O with PZR	off	off	on	on	off	Test PZR Effect, Conservative Model
5	D_2O with PZR & I/C	on	on	on	on	off	Access Real System

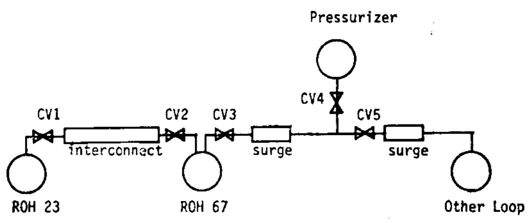

Fig. 2. Control Valves Modelling of System

anlayzed and the light water case as the coolant is selected as a code verification.

IV-2. Results and Discussions

IV-2. 1. Code Verification with H_2O Properties (Case 1)

The ATHER/MOD-I code is verified when verifying the ATHER code,[5] but as an addition, it is verified through solving the stability problem by using the H_2O properties and comparing the results with the reference calculation.[2]

The initial steady state for this case is obtained as follows;

Core Power	: full power
Power Shape	: cosine
RIH Temperature	: 519.8 °F
RIH Pressure	: 1637.3 psia
ROH Temperature	: 591.5 °F
ROH Pressure	: 1449 psia
ROH Enthalpy	: 628 Btu/lb
ROH Quality	: 4.08%
System Flowrate	: 4022lb/sec
Smoothing Parameter	: 0.09

The inlet feeder flow variations are shown in figure 3 and it shows diverging flow oscillations. The comparisons with the reference calculation are shown in table 3. They show a little differences but still are in good agreements. These differences are considered to come from the differences such as the number of nodes, system initial status, analytic models and methods and used correlations such as for the slip and drift, etc.

In this calculation, the pressurizer, the surge line and the interconnect pipe are excluded from the system model as shown in table 2. This "figure-of-eight" system shows the divergent flow oscillations with the H_2O coolant and the two halves of the system loop are almost 180 degree out of phase.

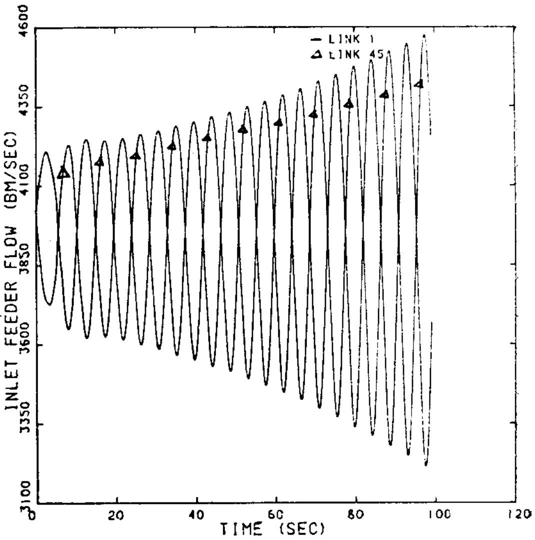

Fig. 3. Inlet Feeder Flow(Case 1)

IV-2. 2. D_2O Case

In this section, the predicted results of the case studies 2, 3, 4, 5 are analyzed. The system models are shown in table 2 and figure 2. And the results are summarized in table 3.

IV-2. 2. 1. D_2O with the Most Adverse System Model(Case 2)

Figures 4, 5, 6 show the inlet feeder flow, ROH pressure and ROH void fraction transients under the standard perturbation. The PHTS flow oscillations are divergent and develop to almost limiting cycle oscillations bounded by +8% and −10%. The period of oscillations which is dependent on the transit time through the two phase region is about 10.3 seconds and the oscillations are 180 degree out of phase for the two halves of the loop. Above results mean that the "figure-of-eight" symmetric system damping is not sufficiently high so to have the flow instability problem.

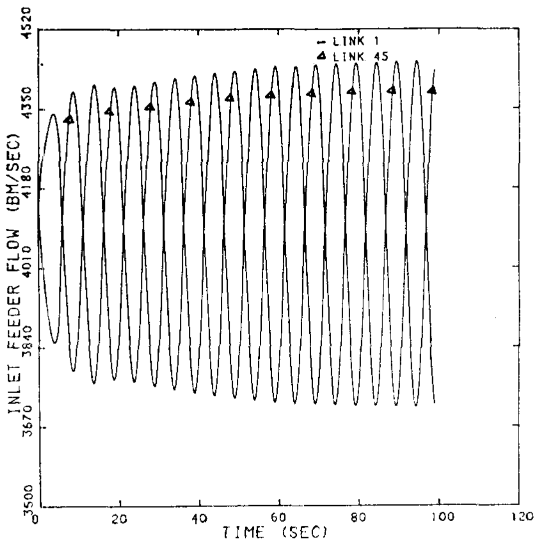

Fig. 4. Inlet Feeder Flow(Case 2)

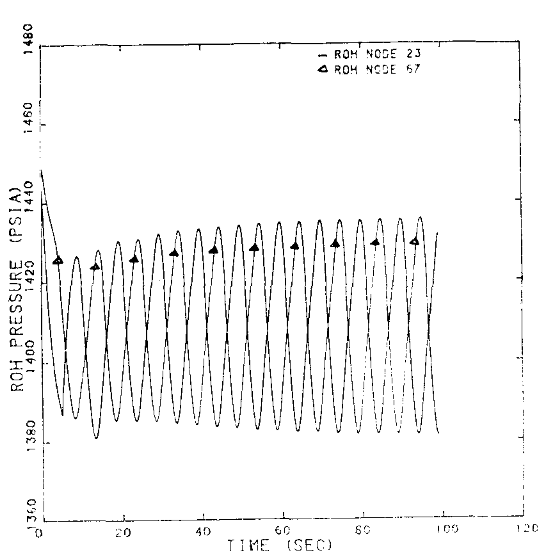

Fig. 5. ROH Pressure (Case 2)

With the initiation of the perturbation at the ROH node 23, the inlet feeder flow at link 1 begins to increase and the inlet feeder flow at link 45 begins to decrease. And at the same time, both ROH's(node 23 and 67) pressure decrease and both ROH's void increase due to the mass extraction by the perturbation. But after the termination of the perturbation, the ROH pressure at node 23 begins to increase and

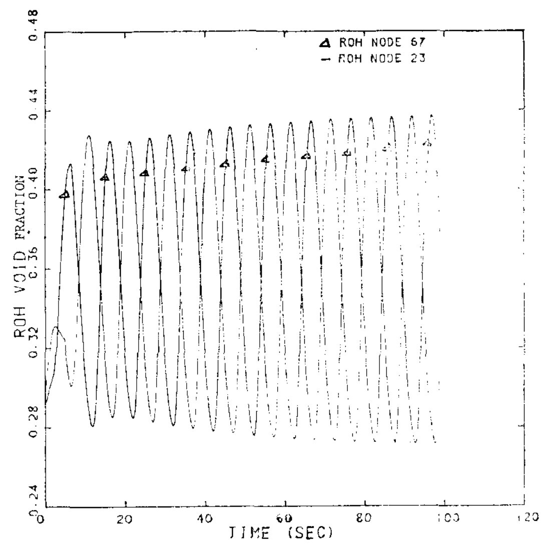

Fig. 6. ROH Void Fraction(Case 2)

to collapse the void. This causes the decrease of the void at the ROH node 23, meanwhile the pressure still decreasing and the void still increasing at ROH node 67. This pressure increase at node 23 makes the inlet feeder flow at link 1 to decrease and the inlet feeder flow at link 45 to increase with the help of acceleration by the pressure decrease at node 67. The increased flow at link 45 causes the void at node 67 starts to decrease and the decreased flow at link 1 causes the void at node 23 to increase simultaneously. This procedure develops until the frictional dissipation is balanced and after that, the gross flow reverses this process. As shown in the figures, due to the low symmetric system damping and the positive flow-quality-void feedback with the core power generation, the flow oscillations develop to almost limiting cycle oscillations. Since the single phase regions are almost incompressible, the inlet feeder flow oscillations and the ROH pressure oscillations are almost in phase. But the ROH void oscillations show 3~4 seconds of phase delay comparing with the inlet feeder flow oscillations, which comes from the enthalpy transport delay.

IV-2. 2. 2. D_2O with Interconnect(Cale 3)

Figures 7, 8, 9 show the inlet feeder flow, ROH pressure and the interconnect flow transients under the standard perturbation. As shown in the figures, the PHTS inlet feeder flow oscillations are convergent with the maximum overshoot of 5% and the settling time of about 80 seconds with the input amplitude of percent of delta as 0.7%. The oscillation period is about 9.7 seconds

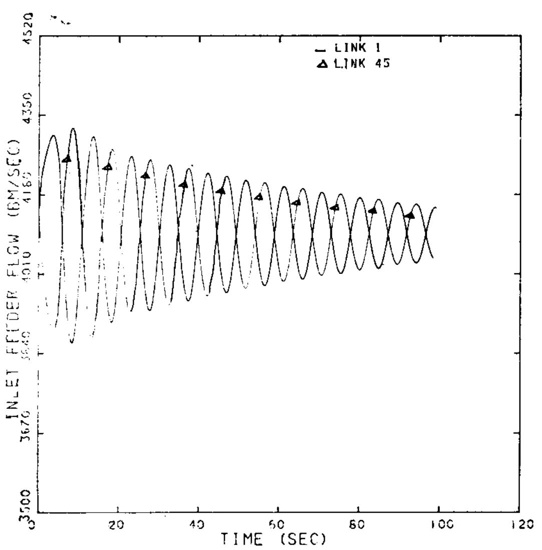

Fig. 7. Inlet Feeder Flow(Case 3)

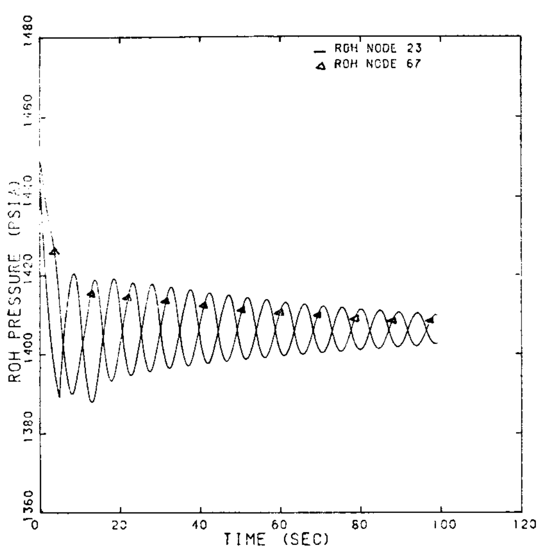

Fig. 8. ROH Pressure(Case 3)

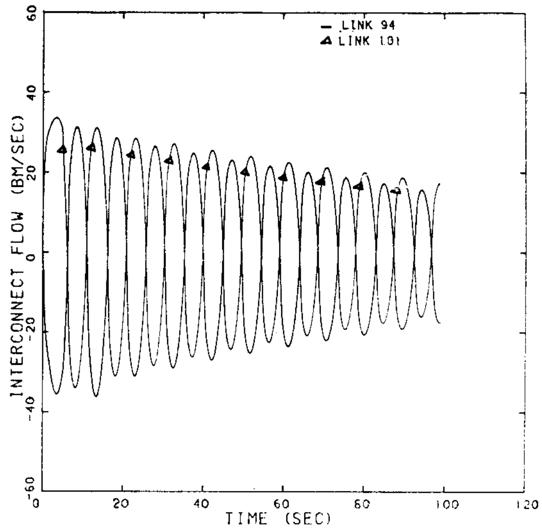

Fig. 9. Internonnect Flow(Case 3)

about 0.5 second shorter than the case 2. They are due to the fact that the driving force for the liquid velocity, the pressure, is transmitted to another ROH in the form of flow through the interconnect. And this convergent flow oscillations mean that the PHTS stability is remarkably enhanced by the interconnect as the passive installation.

The major positive damping of the PHTS is performed by the interconnect flow between the two compressible regions, ROH's. The interconnect flow oscillates to damp out the system oscillations. The interconnect maximum flow during the transients is about 33lb/sec at the initiation of the transients and at 100 seconds around, it decreases to about 20lb/sec. The comparisons of the interconnect flow oscillations with the inlet feeder flow oscillations and the ROH pressure oscillations show that the interconnect makes the system to be stable keeipng in good phase with the pressure oscillations between ROH's without disturbing the inlet feeder flow oscillations.

IV-2. 2. 3. D_2O with Pressurizer(Case 4)

Figures 10, 11 show the inlet feeder flow and

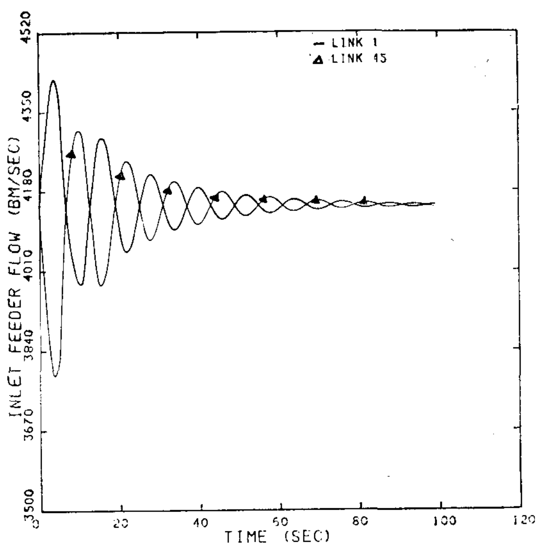

Fig. 10. Inlet Feeder Flow(Case 4)

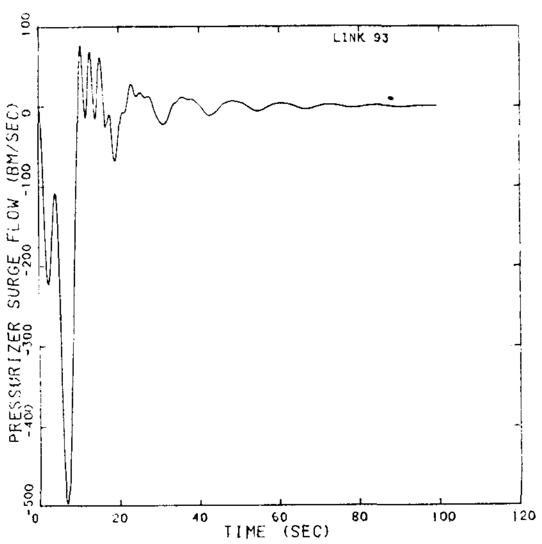

Fig.11. Pressurizer Surge Flow(Case 4)

the pressurizer surge flow transients. As shown in the figures, the PHTS inlet feeder flow oscillations are convergent with the maximum overshoot of 6.5% and the settling time of about 45 seconds with the input amplitude of percent of delta as 0.7%. Comparing with case 3, this case shows the more stable system responses whereas the maximum overshoot is higher; this is due to the large pressurizer outsurge flow at the initiation of the transients. Above results mean that the PHTS inherent damping by pressurizer itself is sufficient to ensure the system stability.

The major positive damping of the PHTS is the pressurizer surge flow. The magnitude of the pressurizer surge flow is very high at the initial stages of the transients so that the stabilizing effect is higher than the case 3 even though the higher maximum overshoot. In this case, conservative pressurizer model is used by neglecting the other loop effect and the pressure control actions so that the results do not predict the real system responses, but they show more conservative results.

IV-2.2.4. D_2O with Interconnect and Pressurizer(Case 5)

Figure 12 shows the inlet feeder flow. As shown in the figure, the PHTS flow oscillations are highly convergent with the interconnect and including the pressurizer modelling. The maximum overshoot is 6% and the settling time is about 25 seconds with the input amplitude of percent of delta as 0.7%. These convergent flow oscillations mean that the PHTS stability is highly creditted.

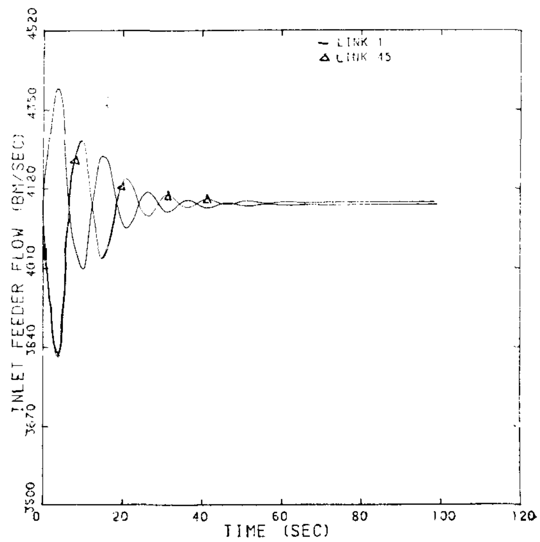

Fig. 12. Inlet Feeder Flow(Case 5)

Table 3. Results of Case Studies

Case 1

	Ref.	Case 1
Period	12 sec	10 sec
Out of Phase	180	180
Overshoot		
20 sec	4%	5%
90 sec	17%	14%

- Divergent Flow Oscillation
- Code Verification

Case 2

	Maximum Overshoot	Settling Time	Remarks
Case 2	N/A	N/A	Divergent
Case 3	5%	80 sec	Convergent
Case 4	6.5%	45 sec	Convergent
Case 5	6%	25 snc	Convergent

- Percent Delta =0.7%

This analysis is the closest to the real system responses even though the conservative pressurizer modelling is adopted. The system dampings by both the pressurizer and the interconnect are very high to make the system stable outstandingly. The discrepancy of the converged inlet feeder flow at 60 seconds around is due to the asymmetric system nodalization and the ignorance of pressure control actions and other loop effect linked by the pressurizer.

V. Conclusions

In this paper, 600 MW(e) CANDU PHTS flow instability phenomena are investigated under the standard perturbation. The ATHER/MOD-I code is improved and verified in predicting the stability analysis. For the "figure-of-eight" symmetric system, the PHTS shows divergent flow oscillations, that is, the PHTS dampings, flow restrictions, without the interconnect and the pressurizer modelling are not sufficiently high to ensure the system stability. With the interconnect, the PHTS stability is remarkably enhanced to be the stable system, that is, the design change can effectively stabilize the system without disturbing the flow oscillations. However, even with the conservative pressurizer modelling, the PHTS shows more convergent flow oscillations than with interconnect, which means that the inherent system damping by the pressurizer itself is sufficient to ensure the system stability. With the interconnect and including the pressurizer modelling, the PHTS stability is highly credited.

Conclusively, the flow instability is found to occur with the most adverse symmetric system modelling. But, the inherent system dampings by such as pressurizer can credit the PHTS stability without the interconnect, even though the interconnect has the highly stabilizing effect.

References

1. "600 MW(e) CANDU-PHW Wolsung-I Nuclear Power Plant for Korea Electric Compnay Safety Report", Rev., AECL, (1981).
2. B.R. Ajmera, et al., "600 MW(e) CANDU Heat Transport System Flow Stablity", TDS-xx-33100-440-001, AECL, (1981).
3. R.S. Hart and J.Yip, "Wolsung-I Main Heat Transport System", DD-59-33100/63310, Rev. 1, (Jun. 1977).
4. Lee, W.J. "ATHER/MOD-I, Accidental Thermal Hydraulic Evaluation of Reactor", KAERI, to be published.
5. Kim, J.S., Lee, W.J. et al., "The Safety Evaluation of PHWR Fuel", KAERI/RR-345/1981. (May. 1982).
6. Richard C. Dorf, "Modern Control Systems", 3rd Edition, Adison Wesley Publishing Company (1980).
7. T.A. Porshing, et al, "Stable Numerical Integration of Conservation Equations for Hydraulic Networks," Nucl. Sci. Eng. Vol.43, 218-225, (1971).
8. W.M. Bryce, "A New Flow Dependent Slip Correlation which gives Hyperbolic Steam Water Mixture Flow Equation", European Two-Phase

Flow Group Meeting, Grenoble, France, (1977).

9. J.A. Homes, "The Drift-Flux Correlation in RELAP-UK", AEEW-R1143, (1977).
10. Y. Ogniewicz and E.E. Merlo, "Effect of ROH interconnecting pipe on Loss of Primary Pressure Control Accidents(Depressurization) for 600 MW (e) Reactors," TTR-46, AECL, (1982).
11. Lee, W.J. "D_2O, Heavy Water Steam Table Generation Program", KAERI, to be published.
12. Lee, W.J. "BULPLT, General Plotting Program for CALCOM 960 Plotter", KAERI, to be published.
13. P.G. Hill, et al, "Fundamental Equation of State for Heavy Water", J. Phy, Chem. Ref, Data, Vol. 11, No.1, (1982).
14. P.G. Hill, et al, "Saturation States of Heavy Water", J. Phy. Chem, Ref. Data, Vol.9, No. 3, (1980).
15. R.L. Burden, et al, "Numerical Analysis", Prindle, Weber & Schmidt, (1979).
16. E.E. Merle, et al, "HYDNA-III Program Description", TDAI-205, AECL, (1980).
17. Shuji Abe, et al, "Viscosity of Gaseous D_2O at High Pressures", Bull. of JSME, Vol. 21, No. 151, (Jan. 1978).
18. M.R. Lin, et al, "FIREBIRD-III Program Descripton", AECL-7533, (Sep. 1979).