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A Study on the Static Instability of a Once-Through Steam Generator with Modular Feedwater Lines

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1. Introduction

Static flow instability of a once-through steam generator (OTSG) with modular feedwater lines (MFLs) is an instability related to the change of a flow direction in individual steam generating U-shaped channels operating at a given pressure difference. The nature of a static instability is close to a Ledinegg instability [1] related to the presence of multiple flows at the full hydraulic curve of a U-shaped channel. In this paper, the conditions for a reverse flow for the OTSG with U-shaped MFLs are studied. From the results of the studies, it is revealed that the change of a flow direction in the MFL is due to a boiling of the feedwater in the downcomer branch of the U-shaped MFL and that multiple flows start in an area of the extremes corresponding to the minimum pressure difference of the hydraulic curves. Calculation models for predicting a threshold of a static instability for the OTSG of interest is proposed and the analysis results are compared with the experimental data.

2. General Description for Various Types of Enclosure Assemblies of the MFLs

Steam generator cassette (SGC) of interest in this study is a once-through modular type and it is installed inside the reactor vessel of an integral type reactor. Modular feedwater line (MFL) penetrates the upper part of the reactor vessel side wall and is connected to the bottom head of the SGC. Modular steam line (MSL) also penetrates the upper part of the reactor vessel side wall and it is connected to the top head of the SGC (Fig. 1). One SGC consists of six MFLs and six MSLs. Schematically, as seen from the SGC sectional view, the secondary circuit of each module represents a U-shaped channel formed by the MFL located at the downcomer section and the active part of the SGC located at the riser section. With such a geometrical configuration of a long U-shaped channel of the MFL, a sufficient heating of the feedwater in the MFL may cause a atatic flow instability especially at low flow and low pressure conditions. Due to these design characteristics of the MFL and MSL layout, the MFLs are enclosed by various types of cylindrical heat structures (called an enclosure assembly or shortly an assembly) along a flow path.

The geometrical flow structure of the Nozzle Assembly (NA) is quite complex. The MFLs are enclosed by a thick cylindrical metal enclosure over which a bulk steam flows. With such a geometrical configuration, there can be heat loss from the steam to the feedwater in the MFLs at the NA, resulting in a degradation of the steam quality (or superheat) from the SGC tube exit and an increase of the feedwater temperature.

At downstream of the NA before a turning of the feedwater flow to a downward direction, the MFLs are enclosed by the Horizontal Assembly (HA) of a hollow cylinder, inside which a nearly stagnant water exists and in which six holes of the MSLs penetrate. The stagnant water inside the HA functions as a thermal barrier against a heat transfer from a hot side of the primary coolant to a cold side of the feedwater. A sectional view of the HA is shown in the bottom-left area of Fig. 1.

The Vertical Assembly (VA) consists of the MFLs, a nearly stagnant water, and a thin hollow metal cylinder.

Due to a manufacturing problem, there are two regions of the MFLs which are not enclosed by an enclosure assembly: Top Bared MFLs (TBM) and Bottom Bared MFLs (BBM). Huge amount of heat is transferred to the feedwater through these bared MFLs.

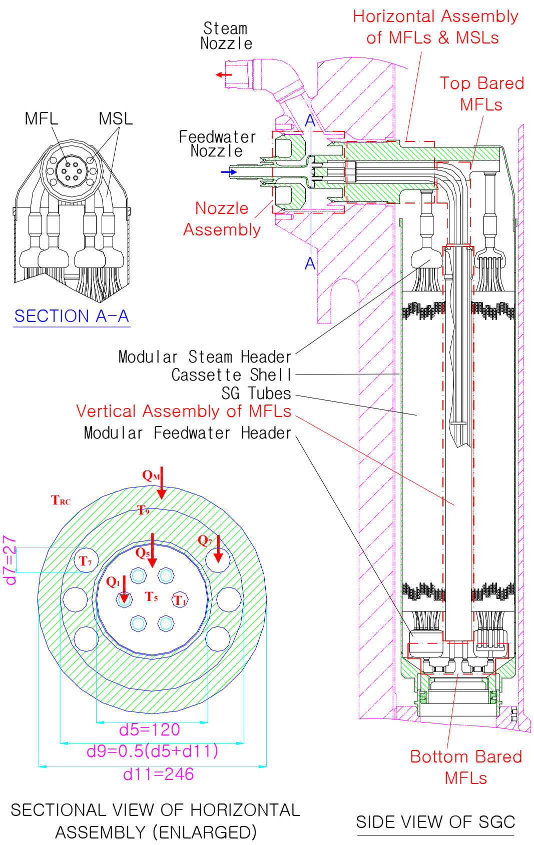

Fig. 1. The SGC with a Sectional View of the Horizontal Assembly of the MFLs and MSLs

3. Experimental Study on Static Instability

Experimental investigation was conducted to find a minimum allowable feedwater flowrate. Test model was developed to carry out thermal-hydraulic performance tests for the purpose of a design confirmation and an acquisition of information on the limiting conditions for a safe operation of the prototype SGC. Major measured parameters and their locations are shown in the schematic diagram of the test facility (Fig. 2).

Tests were conducted at a stepwise decrease (10%→7.5(or 8)%→3%→2%→1%) of the feedwater flowrate for all the given cases. The recording of the feedwater flowrate sensor readings did not indicate any definite conclusion on the nature of the hydrodynamic processes while running the test model because they are measured from outside the SGC model. As for the other parameters there was an increase in the relative amplitude of the pressure drop fluctuations as well as the steam temperature fluctuations, which were indirect evidence of a hydrodynamic instability.

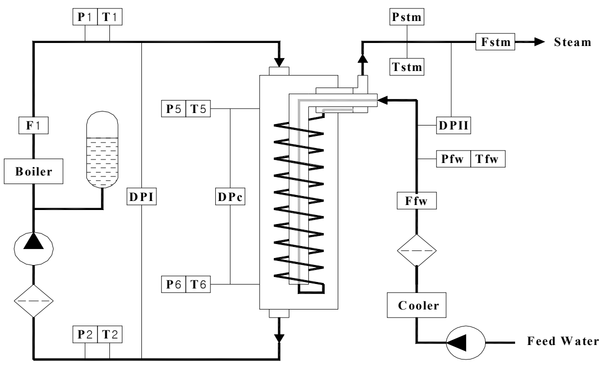

Fig. 2. Schematic Diagram of SG Test Facility

4. Results and Discussions

Based on the heat transfer and pressure drop models developed in this study, calculations have been conducted to predict the $Ffw_{boiling}$ and $Ffw_{boundary}$ and subcooled margin at the MFL header of the SGC. We selected 6 cases for the static instability analysis by considering actual operational conditions. These cases are given in Table 1. Table 2 shows the summary of the comparison of the analysis results with the experimental results.

Table 1. Analysis Cases for Static Flow Instability

Cases	F1, %	Ffw, %	T1, ℃	Tfw, ℃	Pstm, MPa
I	100	1~20	310	50	3.45
II	100	1~20	310	140	3.40
III	50	1~20	310	50	1.6
IV	15	1~20	310	140	3.45
V	100	1~20	240	140	2.0
VI	15	1~20	240	140	2.0

Note) the meaning of parameters is shown in Fig. 2.

Table 2. Summary of the Comparison of the Results

Cases	Fluctuated variables	Onset of static instability	
		Experiment results	Analytical prediction
II	DPII Tstm Fstm	**3.0%** ≤ Ffw < 7.5%	Ffw = 7.4%
III	DPII Tstm Fstm	**7.5%** ≤ Ffw < 10.0%	Ffw = 7.3%
IV	Tstm	**3.0%** ≤ Ffw < 8.0%	Ffw = 4.6%
V	Tstm	**3.0%** ≤ Ffw < 8.5%	Ffw = 3.8%
VI	Tstm	**3.0%** ≤ Ffw < 8.0%	Ffw = 2.4%

5. Conclusion

By using the thermal hydraulic models (not shown in this paper) developed for understanding a flow instability known as a static instability for a system with U-shaped MFLs, a full hydraulic curve with load changes was generated for various operational conditions. This curve enabled us to predict the onset of a static instability for an OTSG with U-shaped MFLs.

It was revealed through a theoretical analysis that a boiling in the MFL due to an over heating of the feedwater is the main source for an occurrence of a static instability for the OTSG.

From the comparisons of the analysis results with the experimental results, it is concluded that a limiting load (feedwater flowrate) for a stable operation of an OTSG for a given operational condition can be predicted by using the analysis model developed in this study.

REFERENCES

[1] Ledinegg, M., 1938, “Instability of Flow during Natural and Forced Circulation”, Die Warme 61:8, AEC-tr-1861 (1954).