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Evaluation of SG Hydraulic Instability for Kori Units 3 & 4 and Yonggwang Units 1 & 2

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1. Introduction

Hydrodynamic instability is a potential problem in any fluid system where boiling takes place. Instability, if present in the pressurized water reactor steam generator, will result in periodic oscillation in water level, steam flow, feedwater flow and flow through the circulation loop. Density wave instability is the most common type encountered in the boiling heat exchanger. The density wave instability results from an unfavorable distribution of pressure drop through the circulation loop.[1]

In this paper, some fundamental parameters which can affect the intrinsic, hydrodynamic instability are evaluated. This paper covers also how to prevent instability from occurrence for Kori Units 3&4 and Yonggwang Units 1&2.

2. Effect of Stability Parameters

Three basic parameters on density wave instability are evaluated. These parameters are as follows.

1) Downcomer water subcooling
2) Power level
3) Tube support plate(TSP) flow area

2.1 Inlet Subcooling

An increase in the inlet subcooling tends to be destabilizing if it is below the threshold subcooling. If above the threshold, an increase in the inlet subcooling is stabilizing.

There are two competing mechanisms: length to boiling and single phase friction damping. For zero inlet subcooling, water will boil immediately upon entering the tube bundle. It results in neither single-phase friction damping nor boiling length. Therefore there is no time delay in the single-phase region and no inherent fluctuation of the boiling boundary. The result is a more stable system. Any increase in the inlet subcooling in this low subcooling range tends to depart from the stable condition. However, if the inlet subcooling is large enough then the friction damping dominates, which is stabilizing.

An increase in feedwater temperature decreases downcomer water subcooling, which results in a relatively larger damping factor (in negative value). Figure 1 depicts the damping factor versus feedwater temperature. The larger the negative damping factor is, the more stable the system is. If the damping factor is positive, the oscillation could diverge exponentially.

For the steam generator conditions, the downcomer subcooling is apparently below the threshold subcooling. Therefore, a decrease in the inlet subcooling is desirable for it would stabilize the boiling flow.

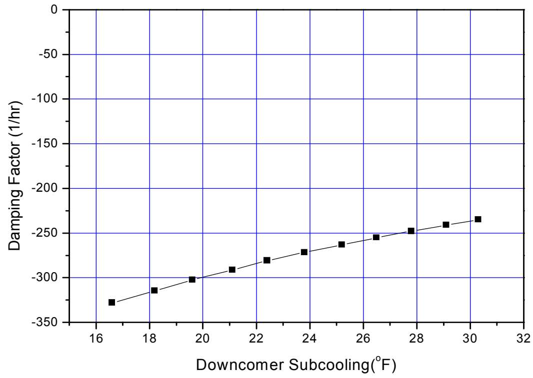

Figure 1. Damping factor vs. Inlet Subcooling

2.2 Power Level

Figure 2 depicts the same information. The higher the power level is, the more the vapor (or void fraction) in the tube bundle is, in particular in the upper tube bundle. Therefore, the pressure drop in the two-phase flow zone is higher than that in the single phase water zone, such as that in the downcomer. Thus, the stability margin (i.e., the negative damping factor) becomes smaller as power level gets higher.

There is however a turning point along the power level curve, at about the 50% point. An increase in power above this point reduces the stability margin. The dominating factor in controlling two-phase pressure drop is the steam void fraction. The higher the power level the larger the void fraction, and thus the bigger the two-phase flow pressure drop.

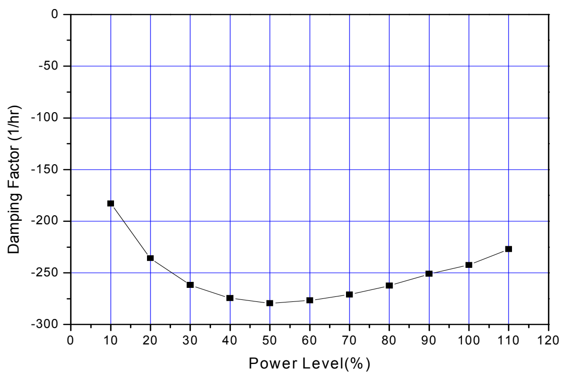

Figure 2. Damping factor vs. power level

2.3 TSP Flow Area

A reduction of the TSP flow area causes an increase in pressure drop within the two-phase flow zone, which destabilizes the boiling flow through the tube bundle. Although pressure drop in the two-phase zone is also dissipative and thus stabilizing, oscillation in the incoming flow rate does not totally dissipate itself in pressure drop. Pressure drop depends on flow rate and void fraction. An increase in the flow rate will lead to an increase in the pressure drop and a decrease in the void fraction. If the void fraction remains the same then the oscillation can dissipate totally through a complete pressure drop. The decrease in the void fraction reduces the pressure drop, and thus damping of the flow increase is incomplete. The higher the impedance in the two-phase flow zone is, the less damping is, and thus the smaller the stability margin. This feedback between the flow and void can lead to flow oscillation. Figure 3 shows damping factor versus flow area reduction.

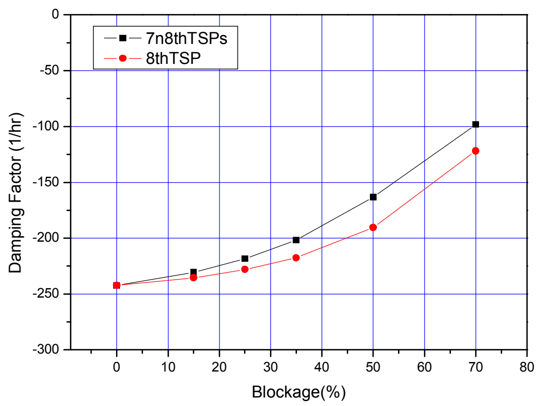

Figure 3. Damping factor vs. TSP hole blockage

3. Threshold Power of Instability

Assessment of threshold of instability power is done for Kori Units 3&4 and Yonggwang Units 1&2. As shown, for each blockage the damping factor curve turns towards more negative damping factor. A more negative damping factor implies a greater margin to instability.

Some threshold values of damping factor could lead to instability. According to experience of an American nuclear power plant, these threshold values have a lower bound of -120 hr^{-1}, best estimate of -92 hr^{-1} and an upper bound of -54 hr^{-1}[2].

Figure 4 depicts how to read the range of blockage that could lead to instability for a power level. For example, at 100% power, instability could take place when blockage is 62% (lower bound) or 68% (best estimate).

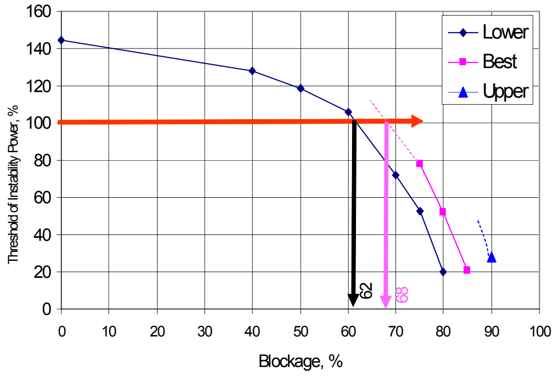

Figure 4. Threshold instability power vs. blockage

4. Conclusion

According to the above analyses, we can draw the following conclusions.

1) Steam generators should be stable with any water level oscillations if the design features are not altered during plant operation.

2) If water chemistry is such that blockage of broached holes of tube support plates takes place, then reduced flow area through the plate will increase pressure drop in the two-phase flow zone. Therefore, a density wave instability can develop. The result is oscillations of water level, feedwater flow, steam flow and circulating flow inside tube bundle.

3) Effective way to restore stable operation at full power is to remove the blockage of the broached holes.

4) For Kori Units 3&4 and Yonggwang Units 1&2, instability could take place when blockage is 62% (lower bound) or 68% (best estimate) at 100% power.

REFERENCES

[1] M.H.Hu, Steam Generator Intrinsic Stability, Westinghouse, 1999

[2] J.Y.Lee and M.H.Hu , Summary Report Technical Consultation on Steam Generator Thermal Hydraulic Instability, KRD-ESS-5, Rev. 1, 2005